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This report is a planning tool which provides information on small water treatment systems. The content of this report is directed to the governing bodies responsible for the small water treatment systems so that they can better understand what is required of them by the National Interim Primary Drinking Water Regulations regarding treatment of their water and the related costs. It is directed to the water plant operator or city engineer to assist one in understanding what can be expected of various treatment processes with regard to meeting the maximum contaminant levels (MCL) specified in the regulations. Finally, the report is directed to consulting engineers to assist them in planning for new and/or improved water treatment systems. The report will provide the engineer with treatment techniques, design parameters and cost information in regard to meeting the various MCL's.

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STATE OF THE ART OF SMALL WATER TREATMENT SYSTEMS

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AUGUST 1977

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I. INTRODUCTION

When the National Interim Primary Drinking Water Regulations were promulgated late in 1975, it was estimated that there were about 40,000 community water systems (see Appendix A). Of this total more than 37,000 community systems each served 10,000 or fewer people. Thus, the vast majority of community water systems would be considered small water systems (capacities less than about 5700 m^3/day or 1.5 mgd). A previous study [1] provided technical and economic information for the approximately 3000 community water treatment systems with capacities in excess of 3800 m^3/day (1 mgd).

An economic analysis [2] indicates water systems serving 25-99 persons will need to spend a total of $6.2 – $9.1 million per year on monitoring, capital investment, operation, and maintenance to meet the National Interim Primary Drinking Water Regulations. An equivalent figure of $109.4 – $151.3 million has been estimated for those systems serving from 100 to 9999 persons. The economic impact on a specific system will depend on the degree of treatment required to meet the regulations.

A. PURPOSE

This report is a planning tool which provides information on small water treatment systems. The content of this report is directed to the governing bodies responsible for the small water treatment systems so that they can better understand what is required of them by the National Interim Primary Drinking Water Regulations regarding treatment of their water and the related costs. It is directed to the water plant operator or city engineer to assist one in understanding what can be expected of various treatment processes with regard to meeting the maximum contaminant levels (MCL) specified in the regulations. "Maximum contaminant level" is defined as the maximum permissible level of a contaminant in water when measured at the customer's tap. An exception is turbidity where the maximum permissible level is measured at the water's point of entry to the distribution system. Finally the report is directed to consulting engineers to assist them in planning for new and/or improved water treatment systems. The report will provide the engineer with treatment techniques, design parameters and cost information in regard to meeting the various MCL's.

B. SCOPE

The state of the art of water treatment for small water systems to meet the drinking water regulations is presented in this report. The plant capacities considered range from 230 m^3/day (60,000 gpd) to 5700 m^3/day (1.5 mgd), serving a population of 25 and 10,000 respectively. Discussion of water supply sources compares ground and surface water sources and covers means of protecting these sources from contamination. The MCL's included in the regulations are presented along with applicable treatment techniques and their efficiencies. Unit processes for the treatment of water are discussed and general design parameters have been compiled for each process. These processes include disposal of the treatment plant wastes and laboratory facilities required to monitor the treatment processes. Examples of conventional water treatment processes for turbidity removal, iron removal, chemical softening (heavy metal removal), and ion exchange softening are explained. In addition commercially available water treatment package plants are described. Graphs of capital, operation, and maintenance costs show the costs for each unit process and also for package plants. Examples of how to use the graphs have also been provided to assist the user.

REFERENCES

1. David Volkert and Associates, *Monograph of the Effectiveness and Cost of Water Treatment Processes for the Removal of Specific Contaminants*, 68-01-1833, U.S. Environmental Protection Agency, August, 1974.

2. Energy Resources Company, Inc., *Economic Evaluation of the Promulgated Interim Primary Drinking Water Regulations*, U.S. Environmental Protection Agency, U.S. Dept. of Commerce NTIS PB 248 588, October, 1975.

II. WATER SOURCES

A variety of sources including surface water, ground water and combinations of surface and ground water are used as water supply for small water treatment systems. The selection of a supply source is dependent upon availability, quality and quantity of water. Considering the small community water systems, probably the majority use ground water as the source. The reasons for this will be discussed subsequently.

A. SURFACE WATER

Surface water sources include rivers, streams, lakes and reservoirs. Surface water is generally available across the United States except in the Southwest where surface waters have high total dissolved solids (some are over 1000 mg/l) [1]. These surface waters are generally unsuitable for potable water supply without extensive treatment. Surface waters require at least turbidity removal and disinfection before use as potable water. In some areas of the country, particularly the Midwest and Western areas, the hardness of the surface waters is high enough to require softening. The dissolved oxygen in most surface waters prevents problems associated with iron, manganese, and hydrogen sulfide. The bottom levels of some lakes and reservoirs may contain soluble iron or manganese or hydrogen sulfide, but these contaminants can be avoided by taking water with dissolved oxygen from a higher elevation in the body of water using multilevel intakes. Other surface waters can exhibit special problems with tastes, odors, color, inorganic contaminants, or pollution related contaminants such as pesticides. River water presents additional treatment complications due to seasonal variations in turbidity, mineral content, industrial and sanitary waste discharges and other surface water related problems discussed previously.

Very little protection can be given to some surface water sources. Gross pollution of rivers and lakes can be prevented by the control of waste discharges. Multipurpose reservoirs can receive some protection by proper placement of adequate sanitary facilities. Single purpose water supply reservoirs can be protected by prohibiting or controlling access to the reservoir watershed.

B. GROUND WATER

Ground water is generally available from wells throughout the United States and from springs in some areas. The quality of ground water varies from water needing only disinfection to water needing extensive treatment for removal of total dissolved solids. Ground water can also require softening due to the hardness content. Ground water can contain other substances such as iron, manganese, hydrogen sulfide, carbon dioxide, radionuclides and inorganic contaminants, particularly fluoride and nitrate. Treatment must be provided for each of these if the substances exceed the established limits. Ground water quality is generally constant and should not contain pesticide contaminants. Since ground water is generally accessable and usually requires little treatment, it is usually used as the water supply source for small systems.

Ground water sources can usually be protected by proper well construction and maintenance. Prior to construction the well should be properly located and during construction the well should be protected and properly cased to prevent pollution.

C. COMBINATIONS OF SURFACE AND GROUND WATER

When combinations of surface and ground water are used, the purpose is usually to provide an adequate quantity of water. However, some combinations are used to enhance the quality of the water. In very cold weather surface water may be supplemented with ground water to raise the temperature of the combined water and speed chemical reactions. In other instances a combination of surface and ground water might be used in a split treatment softening process. For most small systems a combination of surface and ground water would not be economically justifiable.

D. ALTERNATIVES TO TREATMENT

Although most small water systems are in somewhat isolated locations, some are located near larger systems or close to each other. For these small systems a regional water system may be an attractive alternative to extensive treatment for an individual system. Economies of scale dictate a large regional system for those waters requiring significant degrees of treatment.

Another possible alternative for some small systems might be switching water supply sources. A system using a surface water might be able to switch to a ground water source requiring less treatment. Similarly, a system using ground water might consider a surface water source or another ground water aquifer in the area.

REFERENCES

1. Dennis P. Tihansky, "Damage Assessment of Household Water Quality," *Journal of the Environmental Engineering Division – ASCE*, 905-918 (August, 1974).

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American Water Works Association, *Water Quality and Treatment*, 3rd edition, McGraw-Hill, New York, 1971.

Clark, Viessman and Hammer, *Water Supply and Pollution Control*, 2nd edition, International Textbook, Scranton, 1971.

Tihansky, Dennis P., "Damage Assessment of Household Water Quality," *Journal of the Environmental Engineering Division – ASCE*, 905-918 (August, 1974).

III. WATER QUALITY REQUIREMENTS

The primary goal of a water treatment plant is to furnish water safe for human consumption. A second basic objective is the production of water that is appealing to the consumer. Quality guidelines are needed in order to evaluate the suitability of water for public supply purposes. The United States Environmental Protection Agency (USEPA) has developed primary and secondary drinking water standards to replace the United States Public Health Service Standards. Primary standards are based on dangers to health and they are legally enforceable. If primary regulations are exceeded, either additional treatment or an alternative water supply source is required to protect the health of those persons using the water. Secondary regulations are based on aesthetic considerations and are not enforceable by the USEPA, but may be enforced by the States. Violation of these aesthetic standards should be avoided, if possible, to discourage the consumer from turning to some other, unsafe water.

A. NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

The USEPA has published National Interim Primary Drinking Water Regulations (Federal Register, Vol. 40, No. 248, December 24, 1975 & Vol. 41, No. 133, July 9, 1976, see Appendix A) which became effective in June 1977. These primary standards constitute legal requirements for public supplies, because they deal with substances which are hazardous to health. The fact that standards are to be periodically reviewed and can be amended and revised by the USEPA must be considered in determining the need for treatment of a particular water supply.

The primary regulations include standards for inorganic and organic chemicals, turbidity, coliform bacteria and radionuclides. It is of importance that the applicable standards are met at the customer's tap except the turbidity standard which must be met at the point of entry into the distribution system. Therefore, production of water that does not incur contamination from the distribution system is necessary.

The process removal percentages presented for the various contaminants in the following sections are for a single pass through the process. If a single pass will not reduce the contaminant to the required MCL, then multiple stages of the same process or two or more processes in series might be used.

1. Inorganic Chemicals

A discussion of the significance, possible sources, and processes applicable to small public water systems for the removal of each inorganic substance for which limits have been established is included in the following paragraphs.

a. **Arsenic.** Arsenic is highly toxic and the ingestion of as little as 100 mg can result in severe poisoning.[1] The maximum contaminant level for arsenic is 0.05 mg/l. The occurrence of arsenic in the environment is due mainly to natural deposits of the metalloid and to its extensive use in pesticides. Other sources of contamination include manufacturing processes such as tanning, dye manufacture and lead shot manufacture and to its use as a wood preservative. The arsenic concentration of most treated drinking water supplies in the United States ranges from less than 0.03 to 0.10 mg/l.[2] High concentrations of arsenic compounds have been found to occur naturally in some waters of the Western United States.

Selection of a treatment method for arsenic removal is dependent on valence form and initial concentration of the arsenic. The two common valence forms are arsenite and arsenate. Also called arsenic III (this indicates a valence of +3), arsenite is a naturally occurring substance and is usually found only in ground water. Arsenic V (this indicates a valence of +5), or arsenate, can be found in ground water as a naturally occurring substance and in surface water as both a natural and industrial pollutant. In water, both valence forms exist in a relatively insoluble state, except as the sodium or potassium salts.

Various treatment processes will remove arsenic from drinking water. Table 1 [3, 4] lists unit processes and per cent removals of arsenic for each unit process.

Table 1
PROCESSES FOR ARSENIC REMOVAL

Unit Process*	Per Cent Removal
Coagulation, Sedimentation, and Filtration	30–90
Lime Softening	60–90
Ion Exchange**	55–99
Electrodialysis***	80
Reverse Osmosis***	90–95
Adsorption (Alumina)	99

*Additional process information is discussed in the text following this table.
**Anion exchange resin.
***Predicted but not experienced.[3]

Laboratory experiments and pilot plant studies have shown that for coagulation and lime softening, arsenic removals are dependent on the pH of the water, coagulant dose and initial arsenic concentration. The following results [5] were observed during these studies and experiments:

1. Arsenic III removal

   Chemical coagulation or lime softening can achieve adequate removals of arsenicIII, if the arsenic concentration is only slightly above the MCL. Otherwise, oxidation of arsenic III to the arsenic V form is necessary before treatment. Use of oxidants such as ozone and potassium permanganate will be effective on arsenic III. The use of chlorine as an oxidant for arsenic III removal is not advisable as chlorine can react with certain organic materials to produce chloroform and other trihalomethanes.

2. Arsenic V removal

   a. For initial arsenic concentrations less than 1.0 mg/l, coagulant dose (alum or ferric sulfate) of 20 to 30 mg/l and pH between

5.0 and 7.5, arsenic removals of greater than 90 per cent were achieved.

b. For initial arsenic concentrations greater than 1.0 mg/l and other conditions as above, arsenic removals decreased as initial concentration increased. Larger doses of coagulant, however, achieved higher removals.

c. For initial arsenic concentrations up to 10 mg/l and pH of 10.8 and above, lime softening can achieve 95 per cent removals. Below a pH of 10.8, removals decreased to about 30 per cent as the pH decreased to 8.5.

Ferric chloride and ferrous sulfate have also been used successfully as coagulants for arsenic removal.[3]

b. **Barium.** Drinking water should not contain barium in concentrations exceeding 1.0 mg/l because of the toxic effects it has on the heart, blood vessels and nerves.[1] Barium may be found in some ground waters and in runoff from areas where barite and witherite are mined. Industrial applications of barium and its salts include metallurgy, paint manufacture, ceramic and glass manufacture and other processes. Wastes from these plants may contain significant levels of barium contamination. Barium concentrations ranging from 0.0 to 1.55 mg/l have been found in United States treated water supplies.[2] In addition, several cities and subdivisions have been identified by the State of Illinois EPA as using well water sources with barium concentrations greater than the MCL; the highest concentration found was 10 mg/l.[6]

A number of treatment methods can effectively remove barium from drinking water as shown in Table 2.[3, 5]

Studies have shown that lime softening is capable of achieving 90 per cent barium removal if the pH is between 10 and 11 and if the initial barium level is approximately 17 mg/l or less.[5] Below and above this pH range, removals decreased. Conventional coagulation is not recommended for barium removal unless the barium concentration is only slightly above the allowable maximum of 1.0 mg/l. Removals of only 20 to 30 per cent were achieved even when coagulant doses of 120 mg/l were used.

Table 2

PROCESSES FOR BARIUM REMOVAL

Unit Process*	Per Cent Removal
Excess Lime Softening	90
Reverse Osmosis**	90–97
Ion Exchange	95
Electrodialysis**	80

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

Conventional ion exchange softening treatment can very effectively remove barium from water. As a result of the similarity in behavior of hardness and barium in ion exchange treatment, the hardness test can be used to monitor barium during treatment. When blending is used, caution should be exercised to prevent excessive barium levels in the finished water.

c. **Cadmium.** Current evidence indicates that cadmium is biologically a nonessential, nonbeneficial element of high toxic potential.[1] Poisoning from cadmium-contaminated food and beverages has been documented; ingestion of cadmium has been associated with hypertension. Cadmium may leach from galvanized pipes or fixtures used in a water supply system. Only minute traces of cadmium are found in ground water. However, high concentrations may be found in surface waters as a result of wastes from the following industries: electroplating, pesticides, photography, metallurgy and ceramics.

In water supply systems, cadmium has been found in concentrations ranging from less than 0.02 mg/l to 3.94 mg/l.[2] The maximum allowable level of cadmium in drinking water supplies is 0.010 mg/l. Selection of a treatment method depends on whether the cadmium to be removed is soluble or insoluble. Table 3 [3,5] lists unit processes for removal of both insoluble and soluble forms. The chloride, nitrate and sulfate compounds of cadmium are highly soluble in water, but the carbonate and hydroxide compounds are insoluble.

Table 3

PROCESSES FOR CADMIUM REMOVAL

Unit Process*	Per Cent Removal
Removal of soluble forms of cadmium:	
Reverse Osmosis**	90–98
Ion Exchange**	95
Electrodialysis**	80
Stabilization***	100
Removal of insoluble forms of cadmium:	
Coagulation, Sedimentation and Filtration	20–90
Lime Softening	98

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

***Applies only to prevention of corrosion of galvanized piping materials in the distribution system.

Studies have shown that lime softening is effective if the pH is 8.5–11.3. Cadmium removals by coagulation are also dependent on pH with the removal efficiency increasing with increased pH.[5] Based on laboratory studies, coagulation using ferric sulfate has been more effective than using alum. If the pH is increased to greater than 7.5, soluble forms of cadmium will form insoluble compounds and can be removed by coagulation or lime softening as outlined above.

d. **Chromium.** Chromium exists in two common valence forms, III and VI. Chromium is toxic to humans, particularly in the hexavalent state (VI). It can produce lung tumors when inhaled and is a potent sensitizer of the skin.[1] The maximum contaminant level for chromium has been set at 0.05 mg/l.

Sources of chromium contamination in drinking water are largely the result of industrial pollution. Chromium salts are used in the metal finishing industry, in the tanning industry and the manufacture of paints, dyes, explosives, ceramics, paper and many other substances. Chromium compounds may also be present in the discharge of cooling waters where the water has been treated with chromium to inhibit corrosion. The chromium concentration of most treated drinking water supplies ranges from 0.0 to 0.079 mg/l. [2]

If treatment for chromium removal is required, the form of chromium, whether soluble or insoluble, should be identified prior to selection of the treatment system. Chloride, nitrate and sulfate salts of trivalent chromium are readily soluble; however, the hydroxide and carbonate compounds are insoluble. Of the hexavalent salts only sodium, potassium and ammonium chromates are soluble. The corresponding dichromates are also quite soluble. Table 4 [3, 5] lists unit processes for the removal of both insoluble and soluble forms.

Table 4

PROCESSES FOR CHROMIUM REMOVAL

Unit Process*	Per Cent Removal
Removal of soluble forms of chromium:	
Reverse Osmosis**	90–97
Electrodialysis**	80
Ion Exchange**	95
Removal of insoluble forms of chromium III:	
Coagulation, Sedimentation, and Filtration	78–98
Lime Softening	70–98
Removal of insoluble forms of chromium VI:	
Coagulation, Sedimentation, and Filtration	10–98
Lime Softening	10

*Additional process information is discussed in the text following this table.

**Predicted but not experienced. [3]

Removal of insoluble chromium III can be achieved by alum or iron coagulation or by lime softening. Studies have shown that pH has only a slight effect on removals by alum and iron coagulation. Lime softening removals, however, decrease as the pH drops below 10.6.

Insoluble chromium VI is more difficult to remove by conventional treatment than insoluble chromium III. Laboratory studies showed that alum coagulation and lime softening obtained only 10 per cent removal and ferric sulfate coagulation at best removed 35 per cent of chromium VI. Ferrous sulfate coagulation, however, achieved removals of 98 per cent.[5]

Chlorination prior to treatment for chromium removal is not recommended because of the possible oxidation of chromium III to chromium VI. If chlorination before treatment for chromium removal is necessary, ferrous sulfate is recommended as a coagulant. Prechlorination is also not advisable as chlorine can react with certain organic materials to produce trihalomethanes.

e. **Fluoride.** While fluoride is added to some water supplies to aid in prevention of dental caries, some communities have the problem of excessive amount of natural fluoride in their raw water. Excessive fluoride in drinking water supplies produces dental fluorosis.[1] This mottling of the teeth increases with increasing fluoride concentration.

Only a few regions in the United States contain large deposits of fluoride bearing rock. Fluorides in high concentrations are not common in surface waters, but may occur in detrimental concentrations in ground water. Fluorides are used as insecticides, disinfectants, in steel manufacture, for preserving wood, and in the manufacture of glass and enamels. Although they are not normally found in industrial wastes, fluorides may be present as a result of accidental spillage. Fluoride will be introduced to surface water by communities which practice fluoridation and then discharge sanitary wastes to a surface water.

The amount of water, consequently the amount of fluoride, ingested by people in a given community is primarily a function of air temperature. Depending on the annual average air temperature, the maximum allowable level of fluoride ranges from 1.4 to 2.4 mg/l. (Refer to Appendix A for specific allowable levels of fluoride.) Fluoride has been found in water supply systems in concentrations ranging from less than 0.2 mg/l to 8.0 mg/l.[2, 7]

Communities with excessively high natural fluoride levels can utilize any of a variety of defluoridation processes. Processes for fluoride removal are listed in Table 5.[3]

Table 5

PROCESSES FOR FLUORIDE REMOVAL

Unit Process*	Per Cent Removal
Reverse Osmosis**	90–97
Electrodialysis**	80
Ion Exchange/Adsorption**	95
Excess Lime Softening	30–70

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

The method most commonly used for fluoride removal is the ion exchange/adsorption process using either bone char or activated alumina as the exchange resin. Bone char readily removes both fluoride and arsenic; however, arsenic can interfere with fluoride removal when using bone char. Investigations showed that bone char which had adsorbed arsenic could not be regenerated.[4] Activated alumina, however, is readily regenerated when both fluoride and arsenic are removed. Therefore, activated alumina is the recommended medium to use for fluoride removal if the raw water contains both fluoride and arsenic.

Where excess lime softening is used for treatment of high magnesium water, it has been demonstrated that fluoride is removed by coprecipitation with magnesium hydroxide.[8] Fluoride removal is directly related to the amount of magnesium removed. This is indicated by the range of per cent removals in Table 5. If excess lime softening is to be used for fluoride removal, raw water quality may require the addition of magnesium to achieve adequate reduction of fluoride.

f. **Lead.** Drinking water should not contain lead in concentrations exceeding 0.05 mg/l. Excess lead is a serious health hazard especially in children. Lead poisoning in children can cause brain damage and kidney damage sometimes resulting in death.[1] The most likely sources of lead pollution are industrial and mining effluents. Natural waters have been known to contain as much as 0.4 to 0.8 mg/l of lead, but this situation is rare. Another source of lead contamination is lead pipe used for water supply systems. If contamination is due to lead pipes, the best method of control is pipe replacement. Where replacement of the piping system is not practicable, pH control and stabilization is the alternative. Concentration of lead in finished drinking water supplies ranges from 0.0 to 0.64 mg/l.[2]

Lead concentrations in water can be removed by the treatment methods listed in Table 6.[3, 5] Selection of a treatment method is dependent on the form of lead, whether soluble or insoluble. The carbonate and hydroxide compounds of lead are insoluble; the sulfate and various other lead salts are soluble.

Table 6

PROCESSES FOR LEAD REMOVAL

Unit Process*	Per Cent Removal
For removal of soluble forms of lead:	
Reverse Osmosis**	90–99
Electrodialysis**	80
Ion Exchange**	95
Stabilization***	100
For removal of insoluble forms of lead:	
Coagulation, Sedimentation, and Filtration	80–97
Lime Softening	98

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

***Applies only to prevention of corrosion of lead piping materials in the distribution system.

Insoluble forms of lead are the most common, therefore conventional treatment methods of coagulation, sedimentation and filtration, or lime softening will usually be adequate for lead removal. Laboratory studies showed that ferric sulfate is a more effective coagulant than alum in removing lead.[5]

g. **Mercury**. Exposure to mercury and its compounds poses a serious threat to man's health. Continued ingestion of small concentrations of mercury or a one time ingestion of a larger amount can damage the brain and central nervous system.[1] The maximum allowable level of mercury in drinking water is 0.002 mg/l. Most water supplies in the United States do not contain mercury or any of its compounds. Studies indicate that mercury in the United States treated water supplies varies in concentration from 0.0 to 0.033 mg/l.[2]

Industrial and agricultural applications are the most likely source of mercury contamination. Mercury compounds are used in explosives, antiseptics, printing, electroplating, herbicides and fungicides. Mercury may occur in either the inorganic or organic form. The organic form is more important as it is the more toxic form, the form most likely to be found in water, and the more difficult form to remove by conventional treatment.[5] In order to select the proper treatment method, the form of the mercury contaminant, organic or inorganic, should be determined. Listed in Table 7 [3, 5] are treatment methods for mercury removal.

Inorganic mercury removals using coagulation, sedimentation and filtration, or lime softening are dependent on pH of the water.[5] It has been reported that ferric sulfate coagulation achieved 66 per cent removal at pH 7 and 97 per cent removal at pH 8 for a dosage of 18 mg/l on water containing 0.05 mg/l of inorganic mercury. Alum coagulation is less effective; removals of 74 per cent at pH 7 and 38 per cent at pH 8 have been shown. Also, as the turbidity increases, removals by coagulation increase.

Lime softening is moderately effective for inorganic mercury removal, depending on the pH of the water. Studies have shown that in the 10.7 to 11.4 pH range removals were 60 to 80 per cent, but only 30 per cent was removed at pH 9.4.

Table 7

PROCESSES FOR MERCURY REMOVAL

Unit Processes*	Per Cent Removal
For removal of inorganic forms of mercury:	
Coagulation, Sedimentation, and Filtration	38–97
Lime Softening	30–80
Granular Activated Carbon	less than 80
Ion Exchange	95–98
Reverse Osmosis**	90–97
Electrodialysis**	80
For removal of organic forms of mercury:	
Coagulation, Sedimentation, and Filtration	30–85
Granular Activated Carbon	greater than 80
Ion Exchange	95–98
Reverse Osmosis**	90–97
Electrodialysis**	80

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

Activated carbon has been studied for inorganic mercury removal. Powdered activated carbon will increase removals above that obtained with coagulation alone. However, doses required to produce significant increases are much higher than normally used for taste and odor control. Granular activated carbon was found to be fairly effective although removals are dependent on contact time and amount of water treated. Inorganic mercury removals of approximately 80 per cent have been achieved for 15,000 bed volumes of water (a bed volume is equal to the volume of activated carbon used) with 3.5 minutes contact time on water containing 0.020 to 0.029 mg/l of mercury.

Several preliminary experiments indicate that the ion exchange process should be an effective method for inorganic mercury removal. These studies showed that as much as 90 per cent of inorganic mercury can be removed by cation and anion exchange resins in series.

Organic mercury is more difficult to remove from drinking water, by conventional treatment methods, than inorganic mercury. Laboratory experiments and pilot plant studies have shown alum and iron coagulation to achieve lower organic mercury removals than inorganic mercury under the same test conditions. Lime softening was also studied and found to be ineffective for organic mercury removal.

Both powdered and granular activated carbon are effective for organic mercury removal. Approximately 1 mg/l of powdered activated carbon is required for each 0.0001 mg/l of mercury to be removed from water to reach a residual level of 0.002 mg/l. Removal of organic mercury using granular activated carbon was found to be dependent on contact time and amount of water treated, similar to that found for inorganic mercury. Organic mercury removals of approximately 80 per cent have been achieved for 25,000 bed volumes of water with 3.5 minutes contact time on water containing 0.020 to 0.029 mg/l of mercury.

Preliminary studies carried out on ion exchange for organic mercury removal indicate results similar to those for inorganic mercury. Removals of 98 per cent were achieved using cation and anion exchange resins.

h. **Nitrate.** Nitrate in drinking water can cause a temporary blood disorder in infants called methemoglobinemia (blue baby). Serious and occasionally fatal poisonings in infants have occurred following ingestion of waters containing nitrate concentrations greater than 10 mg/l (as nitrogen).[1] Thus the maximum allowable level of nitrate in drinking water is 10 mg/l (as nitrogen). This is equivalent to 45 mg/l of the nitrate ion (NO_3). Studies indicate that nitrate in treated water supply systems varies from 0.02 to 28.2 mg/l (as nitrogen). [2]

Ground waters may acquire nitrates by percolation in areas using nitrate fertilizers and by cesspool leachings. In addition, nitrates may be added to a surface or ground water that receives wastes from chemical fertilizer-producing plants and municipal wastewater treatment plants. Nitrate contamination of ground water supplies can often be prevented by proper well construction. Treatment methods for the removal of nitrate from water are listed in Table 8.[3]

Table 8

PROCESSES FOR NITRATE REMOVAL

Unit Processes*	Per Cent Removal
Reverse Osmosis **	90–97
Electrodialysis**	80
Ion Exchange	98

*Additional process information is discussed in the text following this table.

**Per cent removal based on manufacturers' recommendations.

Nitrate salts are very soluble; therefore, nitrate removal cannot be achieved by processes such as lime softening or coagulation. Presently the most practical method of removing nitrate from drinking water is by ion exchange treatment.[5]

Anion exchange resins can be used to remove nitrate by replacement with chloride. However, pretreatment of water to reduce sulfate, iron or silica concentrations may be required for efficient operation of the exchanger. Sulfate decreases the resins' capacity for nitrate removal, thus more frequent regeneration of the system is required. Iron and silica interfere by clogging the resin, thus preventing the nitrate from being exchanged.

Use of a cation exchange resin and anion exchange resin (demineralization) might be necessary if the chloride level in the finished water becomes undesirably high.

i. Selenium. Selenium in large amounts is toxic to both humans and animals.[1] There is also concern over the possible carcinogenic properties of the element. More recent findings suggest that small amounts may be beneficial. The current limit of selenium in drinking water is 0.01 mg/l. Concentrations of selenium ranging from 0.003 to 0.07 mg/l have been found in water supply systems in the United States.[2]

Some soils, particularly in South Dakota and Wyoming, contain excessive amounts of selenium. Irrigation return flows from these soils may contain undesirably high levels of contamination. Selenium pollution may also result from industrial manufacture of paint, dye, insecticide and rubber.

Prior to selection of a treatment process for removal of selenium, the form of the contaminant should be identified. The two forms, selenium IV (selenite) and selenium VI (selenate), require significantly different treatment methods for effective removal. Refer to Table 9 [3, 5] for appropriate processes for removal of selenium.

Alum and ferric sulfate coagulation, and lime softening are only moderately effective on the removal of selenium IV from water.[5] Of these three methods, tests indicate that ferric sulfate coagulation is the most effective for removal of selenium IV. The best removal was achieved at the low pH of 5.5 and a trend of decreasing removal with increasing pH was observed.

Tests have shown that alum, ferric sulfate and ferrous sulfate coagulation, and lime softening are ineffective methods for selenium VI removal from drinking water. As indicated in Table 9, reverse osmosis and ion exchange are effective methods for removing both forms of selenium.

j. Silver. A study of the toxic effects of silver added to drinking water of rats showed pathologic changes in kidneys, liver, and spleen.[1] The maximum allowable level of silver in drinking water is 0.05 mg/l. Concentrations of silver ranging from 0.0 to 0.03 mg/l have been found in treated water supply systems in the United States.[2] Table 10 [3,5] lists unit processes and their effectiveness for removing silver from water supplies.

Table 9

PROCESSES FOR SELENIUM REMOVAL

Unit Process*	Per Cent Removal
For selenium IV:	
Coagulation, Sedimentation, and Filtration	10–85
Softening	20–45
For selenium VI:	
Coagulation, Sedimentation, and Filtration	0–10
Softening	0–10
For either or both selenium forms:	
Reverse Osmosis	90–97
Electrodialysis**	80
Ion Exchange	95

*Additional process information is discussed in the text preceding this table.

**Predicted but not experienced.[3]

Table 10

PROCESSES FOR SILVER REMOVAL

Unit Process*	Per Cent Removal
Coagulation, Sedimentation, and Filtration	70–90
Lime Softening	70–90
Reverse Osmosis**	90–97
Electrodialysis**	80
Ion Exchange**	95

*Additional process information is discussed in the text following this table.

**Predicted but not experienced.[3]

Both alum and ferric sulfate coagulation are effective in removing silver from drinking water.[5] Alum coagulation removals are pH dependent; above a pH of 8, removals decreased with increasing pH. Both ferric sulfate and lime softening removals increase as the pH is increased.

2. Organic Chemicals

The organic chemicals included in the National Interim Primary Drinking Water Regulations can be divided into two classifications: (a) chlorinated hydrocarbon insecticides and (b) chlorophenoxy herbicides. The insecticides consist of endrin, lindane, methoxychlor and toxaphene; the two herbicides included are 2, 4–D and 2, 4, 5–TP (Silvex).

a. Chlorinated Hydrocarbon Insecticides. Manufactured by numerous companies, these synthetic organic insecticides are widely used, are long-lasting in the environment and are very toxic to humans. The symptoms of poisoning, regardless of the compound involved, are similar. When chlorinated hydrocarbons are absorbed into the body, small amounts are stored in the body fat. Long-range effects of the accumulation of these insecticides in the body are generally unknown. If any of these complex organic compounds are ingested in large amounts, death can result from cardiac or respiratory arrest.[1]

Maximum contaminant levels established for the chlorinated hydrocarbons (refer to Appendix A) are listed as follows:

(a)	Endrin	0.0002	mg/l
(b)	Lindane	0.004	mg/l
(c)	Methoxychlor	0.1	mg/l
(d)	Toxaphene	0.005	mg/l

The 1969 National Community Water Supply Study indicated pesticide concentrations in drinking water are generally lower than the allowable limits.[9] Summarized in Table 11 [5] are unit processes and their effectiveness for removing endrin from water supplies.

Table 11

PROCESSES FOR ENDRIN REMOVAL

Unit Process	Per Cent Removal
Chlorination, 5 mg/l	less than 10
Coagulation, Sedimentation, and Filtration	35
Powdered Activated Carbon*:	
	85
10 mg/l	92
20 mg/l	94
Granular Activated Carbon*, 30 m^3/m^2/day (0.5 gpm/ft^2)	99

*Preceded by coagulation, sedimentation and filtration.

Unit processes applicable for lindane removal are listed in Table 12.[5] Conventional treatment processes are ineffective for reducing lindane levels and therefore are not included in Table 12. Oxidation is also not included in Table 12 as experiments have shown only ozone, in uncommonly high concentrations, to have any appreciable effect in reducing the lindane concentration.

Table 12

PROCESSES FOR LINDANE REMOVAL

Unit Process	Per Cent Removal
Powdered Activated Carbon*:	
5 mg/l	30
10 mg/l	55
20 mg/l	80
Granular Activated Carbon*, 30 m^3/m^2/day (0.5 gpm/ft^2)	99

*Preceded by coagulation, sedimentation and filtration.

Reverse osmosis has also been studied for lindane removal but it is currently impractical for that purpose.[5]

Treatment information is currently not available regarding removal of methoxychlor from drinking water. One publication [5], however, predicts that adsorption with granular activated carbon would effectively remove this contaminant from a water supply.

In regard to removal of toxaphene from drinking water, coagulation, sedimentation, filtration and chlorination have proved ineffective. The recommended treatment method for toxaphene removal is adsorption with activated carbon. Tests have shown a powdered activated carbon dosage of 5 mg/l to reduce toxaphene concentrations by 93 per cent.[5]

b. **Chlorophenoxy Herbicides.** Chemical control of aquatic vegetation is the principal source of the chlorophenoxy herbicides in drinking water. The two herbicides included in the drinking water regulations are 2, 4–D and 2, 4, 5–TP (Silvex). Manufactured and sold under various trade names, these compounds have toxic properties of a generally lower order than chlorinated hydrocarbons.[1] Nevertheless, herbicides should be used carefully so as not to contaminate drinking water.

The maximum allowable levels of 2, 4–D and 2, 4, 5–TP (Silvex) are, 0.1 mg/l and 0.01 mg/l, respectively. The only effective treatment process at this time for removal of 2, 4–D is adsorption using activated carbon. Conventional water treatment processes (coagulation, sedimentation, filtration and oxidation) have been shown to be ineffective for 2, 4–D removal.[5] Reverse osmosis is a potential process for removing 2, 4–D from drinking water. However, sufficient data are not available at this time to recommend it as a practical technique.

Treatment data for the removal of 2, 4, 5–TP (Silvex) are presently not available. It has been assumed that this herbicide would behave in a manner similar to 2, 4, 5–T and Table 13 is a summary of expected removals.[5]

Table 13

PROCESSES FOR 2, 4, 5–TP (SILVEX) REMOVAL*

Unit Process	Per Cent Removal
Chlorination, 5 mg/l	less than 10
Coagulation and Filtration	65
Powdered Activated Carbon:	
5 mg/l	80
10 mg/l	80
20 mg/l	95
Granular Activated Carbon:	99

*Per cent removals listed have been experienced for 2, 4, 5–T and are predicted for 2, 4, 5–TP (Silvex).

3. Turbidity

Turbidity levels of more than 1 to 5 turbidity units may cause interference with disinfection processes. This is the major reason for the maximum contaminant levels of one turbidity unit (monthly average) and five turbidity units (two-day average) as stated in the National Interim Primary Drinking Water Regulations. At the discretion of the State, a maximum of five turbidity units (monthly average) may be allowed if the water supplier can demonstrate that the higher turbidity does not do any of the following:

(a) Interfere with disinfection.
(b) Prevent maintenance of an effective disinfectant agent throughout the distribution system.
(c) Interfere with microbiological determinations.

High turbidity can cause consumers to question the safety of drinking the water.

Turbidity in water may result from suspended and colloidal matter from a variety of sources. It may be caused by microorganisms; mineral substances;

clay or silt and other products of natural erosion; domestic sewage or industrial wastes; and others.

Treatment methods effective for turbidity reduction include various combinations of the processes listed in Table 14.[3]

Table 14

PROCESSES FOR TURBIDITY REMOVAL

Unit Process	Per Cent Removal
Plain Sedimentation	50–95
Coagulation, Sedimentation, and Filtration	80–99

4. Coliform Organisms

It is of the utmost importance that no pathogenic bacteria be present in water intended for human consumption. Direct testing for pathogenic bacteria is difficult and time-consuming, so an indirect test is utilized. A determination is made of the presence of coliform bacteria. Although coliform bacteria are usually nonpathogenic, under certain conditions strains of *E. coli* are capable of causing disease. Under most circumstances, there are probably several thousand coliform bacteria present for each pathogenic organism in contaminated water. Therefore, if coliform bacteria are eliminated from a water, there should be little concern about the water's safety from a bacteriological standpoint. Presence in drinking water of any members of the coliform group indicates deficiencies in treatment of the water.

The National Interim Primary Drinking Water Regulations do not contain a single number as a limit for coliform bacteria. Maximum contaminant levels for coliform bacteria have been established based on the frequency of sampling and the type of test. Refer to Appendix A for coliform bacteria maximum contaminant levels and monitoring frequency. The minimum number of coliform test samples per month depends on the population served by the water system; the larger the population, the greater the number of samples required. The range is from a minimum of one per month for a community system which serves a population of 25 up to 11 per month for a system which serves a population of 10,000.

The membrane filter technique is generally the recommended test method. However, turbidity may interfere with the membrane filter technique, and the multiple tube fermentation technique may have to be employed. When the membrane filter test is used for a facility serving a population of 25 to 10,000, the maximum number of coliform bacteria shall not exceed any of the following:

(a) One per 100 ml as the arithmetic mean of all samples examined per month.

(b) Four per 100 ml in more than one sample per month when less than 20 samples are examined per month.

(c) Four per 100 ml in more than five per cent of the samples when 20 or more are examined per month.

If the multiple tube fermentation technique is used, two standard portion sizes may be used in the test. When 10 ml standard portions are used, coliform bacteria shall not be found in any of the following:

(a) More than 10 per cent of the portions in any month.

(b) Three or more portions in more than one sample when less than 20 samples are examined per month.

(c) Three or more portions in more than five per cent of the samples when 20 or more samples are examined per month.

When 100 ml standard portions are used, coliform bacteria shall not be found in any of the following:

(a) More than 60 per cent of the portions in any month.

(b) Five portions in more than one sample when less than five samples are examined per month.

(c) Five portions in more than 20 per cent of the samples when five or more samples are examined per month.

Bacteria in water sources are primarily the result of organic waste pollution. Sources of this waste include decaying vegetative matter, decaying animal wastes, wastes from food processing plants, untreated sewage and others. In addition to direct contamination, bacteria may be transported to water by air dispersion, birds, and other animals including man.

Disinfection is the primary process for the elimination of bacteria from water. This and other methods of bacterial reduction are listed in Table 15.[3]

Table 15

PROCESSES FOR BACTERIA REDUCTION

Unit Process	Per Cent Removal
Chlorination	99
Ozonation	99
Chlorine Dioxide	99
Sedimentation*	0–99
Coagulation*	Significant amounts
Filtration*	0–99

*These methods do not, in themselves, provide adequate bacterial reduction. However, their use prior to disinfection may significantly lower the costs associated with disinfection.

5. Radiological

Any dose of ionizing radiation may produce harmful effects to human health. Both short term and long term damage to human tissue may result from radioactive contamination. Even if exposure is slight, there may be genetic changes or a cancer may develop.

Radioactivity in public water systems may be generally grouped as naturally occurring or man-made. Radium–226 is the most important of the naturally occurring radionuclides likely to occur in public water systems. Radium is distributed throughout the United States, particularly in midwestern and Rocky Mountain states. Usually found only in ground water, radium may occasionally be found in surface water due to man's activities. In contrast to radium, man-made radioactivity usually occurs in surface water. Sources of man-made radioactivity, in addition to fallout from nuclear weapons testings, are small releases from nuclear power plants, hospitals, and scientific and industrial users of radioactive materials. Maximum contaminant levels for radioactivity in water supply systems are summarized in Table 16.[3] Refer to Appendix A for the radionuclide regulations as published in the Federal Register.

Table 16

MAXIMUM CONTAMINANT LEVELS FOR RADIOACTIVITY

Constituent	Maximum Allowable Level
Combined radium–226 and radium–228	5 pCi/l
Gross alpha particle activity (including radium–226 but excluding radon and uranium)	15 pCi/l
Beta particle and photon radioactivity from man-made radionuclides*	4 mrem/yr

*Based on a 2 liter per day drinking water intake except for tritium and strontium–90. Average annual concentrations of tritium and strontium–90 assumed to produce a dose of 4 mrem/yr are 20,000 and 8 pCi/l, respectively.

Virtually all water sources contain radium, a product of uranium, in trace amounts. Studies indicate the occurrence of radium–226 in United States treated water supplies ranges from 0.0 to 135.9 pCi/l. [2] Also important in health considerations, strontium–90 concentrations in public water supplies are about 1.0 pCi/l, based on available data. Remedial measures for excessive radioactivity in drinking water supplies include dilution of the contaminated water, change of source, and treatment of the contaminated water. If treatment for removal of radionuclides is necessary, conventional methods are usually effective. Listed in Table 17 [5] are various radionuclides and their removal methods and efficiencies.

Table 17

PROCESSES FOR RADIONUCLIDE REMOVAL

Radionuclide	Removal Method	Per Cent Removal
Radium	Ion Exchange Softening	70–98
	Coagulation, Sedimentation, and Filtration	25
	Lime or Lime-Soda Softening	70–90
	Reverse Osmosis	95
Beta and Photon Emitters*	Lime Softening	87–96
	Ion Exchange Softening	75–96
	Reverse Osmosis	90–97

*Removal dependent on specific radioisotope present.

6. Stabilization

While stabilization of water is not directly addressed in the Interim Primary Drinking Water Regulations, it is implied because the maximum contaminant levels for inorganic chemicals are at the consumer's tap. Thus, if the water leaves the treatment plant with all contaminants below their respective maximum contaminant levels, but samples from the distribution system show values above those maximum contaminant levels, then the water quality is in violation of the regulations. Corrosive water can cause solubilization of certain contaminants listed in the Interim Primary Drinking Water Regulations.

Cadmium is present in zinc-galvanized iron pipe and may be dissolved by corrosion. Corrosive water standing in lead pipes can, under certain conditions, solubilize enough lead to exceed the MCL.

A noncorrosive water may be maintained throughout the distribution system in two ways: (1) by maintaining calcium carbonate saturation equilibrium with appropriate pH control, and (2) by introducing additives such as phosphates or silicates. In both cases, a thin protective film is formed on the interior of the piping, thus protecting it from corrosion.

B. SECONDARY DRINKING WATER REGULATIONS

While primary regulations apply to trace elements, compounds, and microoganisms affecting the health of consumers, secondary regulations deal with the aesthetic qualities of drinking water. The contaminants included in these secondary regulations do not have a direct impact on the health of consumers. However, if present in excessive amounts, these contaminants may affect the palatability of the water and encourage the use of possibly unsafe water.

In contrast to primary drinking water regulations, the secondary regulations are not Federally enforceable. As guidelines for suppliers of water, these regulations are meant to be used to improve the quality of water delivered. The secondary drinking water regulations contain recommended maximum contaminant levels for various inorganic chemicals and physical quality characteristics of drinking water. The USEPA has published Proposed National Secondary Drinking Water Regulations (Federal Register, Vol. 42, No. 62, March 31, 1977, see Appendix B). The following substances are included:

1. Chloride

Chloride in concentrations above 250 mg/l causes a salty taste in water which is objectionable to many people.[11] In addition to adverse taste effects, significant increases in customer costs due to deterioration of plumbing and water heaters may be encountered at chloride levels of 500 mg/l. Excessive chloride levels are most often found in highly mineralized ground water. The occurrence of chloride in United States drinking water supplies ranges from 1 to 1,950 mg/l.[2] Chloride is not significantly affected by conventional treatment processes. Reverse osmosis or electrodialysis can effectively remove chloride from drinking water.

2. Color

Color in drinking water becomes objectionable and unaesthetic to most people at levels above 15 color units.[11] The level of this substance does not directly indicate the safety of a drinking water supply. However, highly colored water indicates the potential presence of industrial or domestic wastes as well as mineral or organic materials. Iron and manganese compounds are minerals which can impart undesirable colors to water. Humus, peat, algae, weeds and protozoa are examples of organics which contribute color to water. Some industries whose processes generate color are mining, explosives production, refining, pulp and paper manufacture, and chemical production.

Selection of a treatment method for removal of color is dependent on the nature of the substances causing the color. Treatment methods and removal efficiencies are listed in Table 18.[3]

Table 18

PROCESSES FOR COLOR REMOVAL

Unit Process*	Per Cent Removal
Coagulation	95
Filtration	50–95
Reverse Osmosis	99
Ion Exchange	100
Activated Carbon	100

*Additional process information is included in the following text.

With alum coagulation the best removal is usually achieved with a pH range of 4 to 6.[2] However, for minimum solubility of the coagulant, the pH should be adjusted to greater than 6 prior to filtration. Color coagulation can also be achieved with magnesium hydroxide at a pH greater than 11.0. The per cent removal stated in Table 18 for reverse osmosis applies to all color producing materials with molecular weights greater than 200. Ion exchange, as listed in Table 18, applies to the use of special resins for the removal of organic dye wastes, humates and ligates. The per cent removal listed for activated carbon in Table 18 is for noncolloidal, soluble, aromatic-structured color sources.

3. Copper

The proposed maximum contaminant level of 1.0 mg/l for copper was recommended because copper imparts an undesirable taste to drinking water. Large doses of copper may produce nausea and prolonged ingestion may result in liver damage.[11] Small amounts of copper, however, are generally considered nontoxic. In fact, copper is an essential element in human metabolism.

In water supplies tested across the United States, copper was found in concentrations ranging from 0.0 to 8.35 mg/l.[2] Copper occurs naturally in surface waters. Other sources of copper pollution include the corrosive action of water in copper and brass tubing, industrial effluents and the use of copper compounds for control of algae. Copper salts are used in fungicides, insecticides and various industrial processes such as textile manufacture, tanning, photography, and electroplating.

Removal of copper from drinking water supplies can be accomplished by the treatment methods listed in Table 19.[3]

4. Corrosivity

Corrosion causes various problems in the water distribution system, including tuberculation, leaks, main ruptures, discoloration and loss of chlorine residual. Corrosion is also responsible for an increase in concentrations of trace metals, such as lead, cadmium, iron and copper, as the corrosion damages service lines and household plumbing.

Table 19

PROCESSES FOR COPPER REMOVAL

Unit Process	Per Cent Removal
Coagulation, Sedimentation, and Filtration	*
Softening	*
Reverse Osmosis	90–97
Electrodialysis	80
Ion Exchange	95
Stabilization**	100

*Will reduce copper centration below MCL.[12]

**Applies only to prevention of corrosion of copper piping materials in the distribution system.

Corrosivity is related to pH, alkalinity, dissolved oxygen, total dissolved solids and other factors. Therefore a straight-forward maximum contaminant level has not been proposed.

The adverse effects of corrosion are primarily economic. Therefore, the cost of corrosion control could be offset by the savings from damage prevented. Refer to section III A6, Stabilization for a discussion of methods for controlling corrosion.

5. Foaming Agents

Foaming is an undesirable property of drinking water because it is aesthetically displeasing and is often associated with contamination. Many substances in water will cause foam when the water is agitated or air is entrained. The major class of substances which produce foaming is the anionic surfactant. Contamination of drinking water supplies by this surfactant results from household and industrial synthetic detergent pollution.

Concentrations of anionic surfactants found in drinking waters have ranged from 0 to 2.6 mg/l in well water supplies and from 0 to 5 mg/l in surface water supplies.[11] A proposed maximum contaminant level of 0.5 mg/l, as methylene blue active substances, was chosen to prevent the occurrence of visible foam. The treatment method for removal of foaming agents is adsorption by activated carbon. Removal efficiency ranges from 90 to 100 per cent.[3]

6. Hydrogen Sulfide

Hydrogen sulfide in drinking water often produces very obnoxious odors characteristic of "rotten eggs". Corrosion of ferrous metals in well pump assemblies and filters and corrosion of concrete holding and distribution facilities occurs when hydrogen sulfide levels exceed 0.5 mg/l.[11] Hydrogen sulfide is often caused by microbial action on organic matter or reduction of sulfate ions to sulfide by bacteria and can be found in both ground and surface waters. In addition to its offensive odor and corrosive tendencies, hydrogen sulfide in association with soluble iron produces black stains on laundered items and black deposits on piping and fixtures.

Hydrogen sulfide odor is usually identifiable at concentrations of a few hundredths of a milligram per liter. The proposed maximum level for hydrogen sulfide is 0.05 mg/l. Treatment methods for removal of hydrogen sulfide from drinking water include aeration, which is usually not sufficient by itself, followed by chemical oxidation. For waters with a constant hydrogen sulfide odor, aeration may produce a fine elemental sulfur precipitate which will require coagulation, sedimentation and filtration for removal.

7. Iron

Iron is a highly objectionable constituent of water supplies. It may impart brownish discolorations to laundered goods or a bitter or astringent taste to water. The proposed maximum level of iron in drinking water is 0.3 mg/l. Normal diets contain 7 to 35 mg per day and average 16 mg.[11] Therefore, the amount of iron permitted in water is small compared to the amount normally consumed and does not have toxicological significance. Sources of iron pollution include iron-bearing ground water, acid mine drainage, iron-bearing industrial wastes and corrosion of iron and its alloys. The concentration of iron in well-aerated surface water is usually low. Treatment methods for iron removal are listed in Table 20.[3]

Table 20

PROCESSES FOR IRON REMOVAL

Unit Process	Per Cent Removal
Oxidation	*
Reverse Osmosis	90–99
Electrodialysis	80
Ion Exchange	95
Diatomite Filtration	*
Stabilization**	100
Coagulation, Sedimentation, and Filtration	***

*Additional process information is included in the following text.

**Applies only to prevention of corrosion of iron piping materials in the distribution system.

***Will reduce iron concentration below MCL.[12]

For a detailed discussion of oxidation methods for iron removal, refer to section IV A2, Oxidation. Diatomite filtration can lower iron levels to 0.1 mg/l, if accompanied by preaeration and alkalinity adjustment.[3]

8. Manganese

As for iron, the principal reason for limiting this element is to prevent brownish stains in laundered goods and adverse taste effects in drinking water. From the health standpoint, there are no data to indicate at what level manganese would be harmful when ingested; the daily intake of manganese from a normal diet is about 10 mg.[11]

Manganese concentrations in well-aerated surface waters are rarely over 1.0 mg/l.[3] Deep reservoirs can have undesirable concentrations of manganese in lower portions of the reservoir where reducing conditions prevail. This manganese can cause problems if the water supply intake is located in the deep portion of the reservoir or can cause problems for higher intakes during turnover. In ground water with reducing conditions, high concentrations of manganese may be leached from mineral deposits. Manganese frequently accompanies iron in such ground waters. In addition, manganese is used in the manufacture of paints, steel, glass, and various other materials. It is also used in agriculture to enrich manganese deficient soils and may enter water supply sources through runoff.

The proposed maximum contaminant level for manganese is 0.05 mg/l. Applicable unit processes for removal of manganese are shown in Table 21.[3]

Table 21

PROCESSES FOR MANGANESE REMOVAL

Unit Process	Per Cent Removal
Oxidation	*
Reverse Osmosis	90–99
Electrodialysis	80
Ion Exchange	95
Diatomite Filtration	*
Softening	**

*Additional process information is included in the following text.

**Will reduce manganese concentration below MCL.[12]

For a detailed discussion of oxidation methods for manganese removal, refer to section IV A2, Oxidation. Manganese removal, with preoxidation, to 0.05 mg/l is possible with diatomite filtration.[3]

9. Odor

Odor is an important aesthetic quality of water for domestic use. It is impractical and often impossible to isolate and identify the odor-producing chemical. Therefore, the senses of smell and taste are used to evaluate odors and tastes. In most cases, sensations ascribed to the sense of taste are actually odors.

Undesirable odors in water are caused by vapors from various chemicals including halogens, sulfides, ammonia, turpentine, phenols, cresols, picrates, various hydrocarbons and unsaturated organic compounds. Natural waters may be contaminated with odor producing compounds from weeds, bacteria, fungi, actinomycetes, algae and decaying animal matter. Sewage and industrial wastes may also contribute odorous compounds to water supplies. In addition, some inorganic substances, such as metal ions, impart taste and odor to water.

The proposed maximum contaminant level for odor is a Threshold Odor Number (TON) of 3. For water, the TON is the dilution factor required before the odor is minimally perceptible. Treatment methods for odor removal include aeration, activated carbon, ozonation, superchlorination, chlorine dioxide, and potassium permanganate. Laboratory tests are required to determine the removal effectiveness of each unit process.

10. pH

The proposed range for pH has been set at 6.5 to 8.5, the lower level to prevent appreciable corrosion and the higher level to prevent encrustation, taste and reduced chlorine efficiency. However, the impact of pH in any one water system will vary with the overall chemistry of the water. Thus, a higher or lower pH range may be appropriate under specific conditions. Midwest waters, for example, are usually adjusted during softening to one pH unit above the Langelier stability pH, usually in the low 9's. Chemical addition of lime, soda ash or caustic soda is used to increase pH of a water supply; to decrease pH, carbon dioxide, sulfuric acid or hydrochloric acid may be added during the treatment process.

11. Sulfate

At concentrations above 250 mg/l, sulfates create taste problems; above 600 mg/l, they may have a laxative effect.[11] In addition, high concentrations of sulfate contribute to the formation of scale in boilers and heat exchangers.

Sulfates may enter water sources from tanneries, sulfate-pulp mills, textile mills, and other plants that use sulfate or sulfuric acid. Leachings from gypsum and other common minerals may contaminate sources of water supply. Also, oxidation of sulfides, sulfites, and thiosulfates in surface water yield sulfates.

Concentrations of sulfates in United States water supplies range from less than 0.1 to 770 mg/l.[2] The proposed maximum level of sulfate is 250 mg/l. Treatment methods for sulfate are listed in Table 22.[3]

Table 22

PROCESSES FOR SULFATE REMOVAL

Unit Process	Per Cent Removal
Reverse Osmosis	99
Electrodialysis	80
Ion Exchange	95

12. Total Dissolved Solids (TDS)

TDS may influence the acceptability of water and a high concentration is often associated with excessive hardness, taste, mineral deposition or corrosion. The proposed MCL for TDS is 500 mg/l. Applicable treatment methods for TDS removal are listed in Table 23.[13]

Table 23

PROCESSES FOR TOTAL DISSOLVED SOLIDS REMOVAL

Unit Process*	Per Cent Removal
Chemical Softening	**
Reverse Osmosis	80–99
Electrodialysis	50–90
Ion Exchange	up to 99

*Additional process information is included in the following text.

**See text.

The TDS removal by chemical softening is dependent upon the amount of hardness removed and the relationship between hardness and TDS in the raw water. A recent publication [14] recommended that ion exchange be considered for TDS removal if the maximum raw water TDS concentration is less than 2,000 mg/l. Similarly, the application range for electrodialysis and reverse osmosis is a TDS concentration of 1,000 to 5,000 mg/l and 1,000 to 10,000 mg/l, respectively. If the maximum TDS level falls within the range of more than one of these processes, 1,500 mg/l for example, then an economic comparison should be used to select a specific treatment method.

13. Zinc

Zinc is an essential and beneficial element in human metabolism; the daily adult human intake averages 10–15 mg.[11] Zinc in water does not cause serious adverse health effects but does produce undesirable aesthetic effects. At concentrations of 5 mg/l, zinc can impart an objectionable taste to water. Soluble zinc salts, at 30 mg/l, give a milky appearance to water and at 40 mg/l, they impart a metallic taste.

Industrial uses of zinc salts which may contaminate water sources include the manufacture of dyes, pigments, insecticides and the galvanizing process.

Zinc is rarely found above the trace level in natural waters. Zinc has been found to occur in United States water supplies in concentrations ranging from 0 to 13 mg/l.[2] The proposed maximum level of zinc is 5 mg/l. Unit processes applicable for zinc removal are shown in Table 24.[3]

Table 24

PROCESSES FOR ZINC REMOVAL

Unit Process	Per Cent Removal
Reverse Osmosis	90–97
Electrodialysis	80
Ion Exchange	95
Stabilization*	100
Softening	**

*Applies only to prevention of corrosion of zinc piping materials in the distribution system.

**Will reduce zinc concentration below MCL.[12]

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IV. WATER TREATMENT FACILITIES

Various types and combinations of treatment units are used to produce water suitable for human use. The quality of the source and the quality goals for the finished water form the basis for selecting a method of treatment. Finished water quality goals are given in the preceding section; the means of achieving them will be discussed subsequently.

A. UNIT PROCESSES

Selection of water treatment processes is based on the contaminants to be removed. A variety of unit processes may be required for treatment of the contaminants listed in Section III. Necessary unit processes are generally the same for large or small treatment plants, only scaled down for small facilities. Exceptions to this general rule are discussed where this is not true and a recommendation is given as to the process most applicable to small water treatment systems. This section will, therefore, emphasize the unit processes specifically applicable to water treatment systems serving a population of 25 to 10,000. All design parameters are in terms of plant capacity as opposed to average daily flow.

1. Aeration

As applied to water treatment, the term aeration refers to processes by which water and air are brought into contact with each other for the purpose of transferring volatile substances to or from the water. These volatile substances include oxygen, carbon dioxide, nitrogen, hydrogen sulfide, methane and unidentified organic compounds responsible for tastes and odor. Aeration is not needed at all water treatment plants and a decision as to whether to aerate or not requires careful assessment of the economic and water quality benefits achieved by its use.

The water source is an important selection factor. Surface waters usually exhibit low concentrations of carbon dioxide, no hydrogen sulfide and fairly high dissolved oxygen. Consequently, aeration is not required for the removal or addition of these gases. However, many surface waters do contain traces of volatile organic substances that cause taste and odor problems. While the aeration process is a means of volatile organic matter reduction, conventional aeration systems are not particularly effective because of the low volatility of most taste-and-odor producing compounds. Aeration of surface waters usually cannot be justified on economic grounds.

Ground waters may contain excessive carbon dioxide, methane, hydrogen sulfide, iron, or manganese concentrations. At lime-soda water softening plants, any carbon dioxide dissolved in the water at the point of lime application will consume lime without accompanying softening. For high (>50 mg/l) carbon dioxide concentrations, as encountered in some ground waters, aeration for its removal is probably justified. For concentrations on the order of 10 mg/l or less, aeration is probably not economically valid. Before a decision to aerate for carbon dioxide removal, the cost of maintaining and operating the aerator should be compared to the value of the lime saved and the additional sludge disposal cost.

Aeration will remove methane, a potentially explosive gas sometimes encountered in fairly high concentrations in ground water. Methane removed in appreciable quantities can pose an explosion hazard unless properly disposed.

Aeration is often used for removing hydrogen sulfide from water. It is effective if the hydrogen sulfide concentration is not more than about 1.0 or 2.0 mg/l. Higher concentrations may require special provisions, such as prolonged aeration with diffused air or initial aeration in an atmosphere containing a higher than normal concentration of carbon dioxide followed by a standard aeration process. Such an atmosphere reduces pH, thus releasing the H_2S form of the sulfide and promotes its removal by aeration.

Ground waters are usually deficient in oxygen and aeration is an effective means of adding it. Oxygen addition is desirable if iron and manganese removal is a treatment objective. This is discussed in detail in section IV A2, Oxidation.

The three methods of aeration employed in small water systems are a) gravity, b) mechanical draft, and c) diffused aeration.

a. Gravity Aeration. Various types of gravity aerators have been used in the water treatment industry. The most practical method of gravity aeration for small water treatment systems consists of a stack of multiple trays which are often filled with contact media. Water flows by gravity over the layers of media and trays. The use of mechanical draft aeration with this method of gravity aeration is discussed in the following subsection. Information on media and trays is also included.

b. Mechanical Draft Aeration. This aeration system consists of a tower through which water droplets fall and air ascends in countercurrent flow. The tower usually is made up of a series of trays with wire-mesh, slat or perforated bottoms over which the water is distributed. In most aerators, coarse media such as coke, stone or ceramic balls 5 to 15 cm (2 to 6 in) in diameter are placed in the trays to increase efficiency. Coarse media are especially efficient when the removal of iron and manganese is of importance. The media becomes coated with precipitated oxides of iron and manganese, which serve as catalysts for continuing oxidation reactions. A small basin is often constructed below the aeration unit to allow entrained air to dissipate. The depth of this basin is usually 1.8 m (6 ft); the width and length are frequently the same as those of the aeration unit in question.

Design criteria for mechanical draft aerators are dependent on the type and concentration of the contaminant involved. In aeration towers, five to fifteen trays spaced vertically 30 to 76 cm (12 to 30 in) apart are frequently used. Area requirements for the trays vary from 5.6 to 17.9 cm^2 per m^3/day (23 to 73 ft^2 per mgd); most require less than 7.3 cm^2 per m^3/day (30 ft^2 per mgd). Selection of specific design criteria is usually a joint decision by the manufacturer and engineer. Mechanical draft aeration equipment, of interest for this report, is available in various capacities ranging from 218 to 5,450 m^3/day (40 to 1,000 gpm).

c. Diffused Aeration. Diffused aeration units generally consist of rectangular basins with diffuser equipment located near the bottom. The diffusers distribute compressed air into water through orifices or nozzles in air piping, diffuser plates or tubes. Basins are frequently 2.7 to 4.6 m (9 to 15 ft) deep and 3.1 to 9.2 m (10 to 30 ft) wide. Ratios of width to depth should not exceed 2:1 to insure effective mixing. The length of the basin is governed by the desired retention period, usually 10 to 30 minutes.

The amount of air required depends on the purpose of aeration, but generally ranges from 0.075 to 1.12 m^3 of air per m^3 (0.01 to 0.15 ft^3 of air per gal) of water treated.

Diffused air treatment units conserve the hydraulic head and are not subject to freezing, but require more space than tray aerators. To prevent odor problems, both types of aeration may require housing if hydrogen sulfide is being removed.

d. **Applicability and Recommendations.** Aeration is recommended as a treatment process for carbon dioxide, hydrogen sulfide, and odor removal and as an aid in iron and manganese removal. The decision to use aeration as a treatment process and selection of the type of aeration to employ must be based on the quality of the source of water supply and the contaminants to be removed. An economic analysis should be made to decide between gravity, mechanical draft, and diffused aeration. Mechanical draft aeration is limited in applicability to the sizes of aerators manufactured. Diffused aeration is generally not economically desirable for small water treatment systems. However, if diffused aeration can also serve as a chemical mixing unit as well as an aeration system, then the economics may favor this system.

2. Oxidation

Water treatment utilizes oxidation for various purposes. A number of oxidants can be used to remove or destroy undesirable tastes and odors, to aid in the removal of iron and manganese, and to help improve clarification and color removal. Oxygen, chlorine, and potassium permanganate are the most frequently used oxidizing agents and each is discussed in following sections.

a. **Air.** Aeration is used as a method of adding oxygen to water for oxidation of iron and manganese. For precipitation of 1 mg/l of iron, 0.14 mg/l of oxygen is required, and 0.24 mg/l of oxygen is required for precipitation of 1 mg/l of manganese. Soluble iron is readily oxidized by the addition of oxygen, but manganese cannot be oxidized as easily. However, oxidation of manganese is encouraged if the aeration step provides contact between water and previously precipitated manganese oxide, such as occurs in certain gravity and mechanical draft aerators. Media in these units become manganese-coated and catalytic oxidation of manganese occurs, particularly when the pH has been increased to greater than 8.5. If the level of manganese to be removed is high, aeration processes are usually designed to only initiate oxidation of the manganese. More effective chemical oxidation is then used to achieve acceptable levels of manganese.

Oxidation of organic substances responsible for undesirable tastes and odors using aeration is usually too slow to be of value. However, if dissolved gases such as hydrogen sulfide are the cause of taste and odor problems, aeration will effectively remove them through oxidation and stripping.

b. **Chemical.** Oxidizing chemicals commonly used in water treatment include chlorine, chlorine dioxide, ozone and potassium permanganate. Chlorine and potassium permanganate are the most frequently used chemical oxidants. Ozone and chlorine dioxide require on-site generation and are relatively expensive. Compared to air, chemicals are much stronger oxidizers, therefore more effective. The respective costs for aeration versus chemical oxidation must be compared with the benefits received before a choice of which process to use can be made.

Chlorine, chlorine dioxide and potassium permanganate act effectively as oxidizing agents in destroying taste and odor producing compounds. They also readily oxidize soluble iron and manganese to insoluble oxides. The oxides of iron and manganese are then removed by coagulation, sedimentation and filtration. Difficulties with clarification or color removal which may arise from dissolved organic compounds often can be reduced by the use of chlorine, chlorine dioxide and potassium permanganate. They are added to oxidize interfering organic matter.

Although relatively effective for iron oxidation, chlorine requires longer contact time than potassium permanganate to effectively oxidize manganese at levels greater than 0.2 mg/l. Theoretical amounts of chlorine required are 0.64 mg/l per 1.0 mg/l of iron and 1.3 mg/l per 1.0 mg/l of manganese. In practice, higher values are used to increase the rate of reaction and provide chlorine for competing reactions. The rate of manganese oxidation by chlorine is dependent on pH, chlorine dosage, mixing conditions and other factors. High pH values favor oxidation of manganese.

One main advantage of potassium permanganate oxidation is the high rate of reaction, many times faster than chlorine. Also, potassium permanganate differs from chlorine in that it does not form additional products that might intensify odors normally present. Potassium permanganate is not as pH dependent as chlorine, although the permanganate does react more rapidly as pH increases. Theoretically, 0.94 mg/l of potassium permanganate will oxidize 1.0 mg/l of iron, and 1.92 mg/l of potassium permanganate will oxidize 1.0 mg/l of manganese. In actual practice, the amount of permanganate required is usually less than the theoretical amount. One method of determining the optimum dose of permanganate is to observe the color of the water after application of the oxidant. If a slight pink color persists for a minute or two, the dose is said to be optimum.

As these oxidation processes are not instantaneous, it is desirable to add the oxidant, whether chlorine, chlorine dioxide or potassium permanganate, as early as possible in the treatment process. Early addition of chlorine in the treatment process is inconsistent with prevention of trihalomethane formation; therefore, $KMnO_4$ may be the oxidant of choice. The decision whether to use chlorine or potassium permanganate for oxidation purposes must be based on the contaminant to be removed, on an economic evaluation of the chemicals, and tendencies toward trihalomethane formation.

A method used for removal of iron and manganese is application of potassium permanganate and filtration through manganese dioxide greensand. Greensands are naturally occurring silicates of sodium and aluminum. Manganese dioxide, an oxidizing agent, is affixed to the greensand, and water containing iron and manganese is passed through this material. The manganese dioxide oxidizes the iron and manganese to insoluble forms which precipitate onto the greensand filter. After the oxidizing capacity of manganese dioxide greensand has been depleted, it is regenerated with potassium permanganate. A modification to this process has been developed wherein the manganese dioxide is continuously regenerated with potassium permanganate. Potassium permanganate is continuously fed to the water before entering the filter. The iron and manganese are oxidized by the potassium permanganate and precipitated on the filter. If too little potassium permanganate is added, the iron and manganese are oxidized by the manganese dioxide affixed to the greensand; if too much potassium permanganate is added, the manganese dioxide greensand is regenerated. Thus, uniform amounts of potassium permanganate may be added to a water containing varying concentrations of iron and manganese. Where greensand filtration is preceded by aeration, the amount of precipitated iron influent to the greensand filter can be large. When this situation exists, a layer of crushed anthracite coal on top of the exchange medium is sometimes used to prolong filter runs.

c. Applicability and Recommendations. For small water treatment systems, it is recommended that chlorine be considered before other oxidants since chlorine will normally be used for disinfection, too. If the use of chlorine for oxidation would not be practical, then the use of air or potassium permanganate should be evaluated on an economic basis. Generally, aeration is preferred to use of potassium permanganate for oxidation unless high levels of manganese are to be removed. In that case, the use of potassium permanganate is necessary. Also, if intermittent tastes and odors are a problem, potassium permanganate is preferred economically to aeration. Chemical feed equipment requires a smaller capital expenditure than aeration equipment. In addition, the chemical oxidant would be used on an intermittent basis so operation and maintenance costs would be at a minimum.

Oxidation is recommended as a treatment process for hydrogen sulfide and odor removal, and as an aid in iron and manganese removal.

3. Adsorption

The most important direct applications of adsorption in water treatment are the removal of arsenic, fluoride and organic pollutants. Basically, adsorption is the attraction and accumulation of one substance on the surface of another. Two important adsorptive media in the water industry are activated alumina, often referred to as simply alumina, and activated carbon. Operational characteristics and regenerative techniques will be discussed for both of these adsorptive media.

a. Activated Alumina. Activated alumina is a highly porous and granular form of aluminum oxide. This material is available from several aluminum manufacturers in various mesh sizes and degrees of purity. Alumina is used in the water treatment industry for removing arsenic and fluoride. The treatment process consists of percolating water through a column of the alumina media. Removal of arsenic and fluoride is accomplished by a combination of adsorption and ion exchange.

An activated alumina column consists of alumina media in a contact tank. Either gravity or pressure feed systems can be used. As far as is known, there is very little difference between removal capabilities of these two systems. For sizing the surface area of an alumina column, a surface loading rate of 150 to 175 m^3/m^2/day (2.5 to 3.0 gpm/ft^2) is recommended. The volume, and thus the depth, of media is influenced by the time between regenerations of the alumina. It is advisable to carry out laboratory and pilot-scale studies on the water in question to aid in actual design of the activated alumina column.

Use of the activated alumina process for the removal of arsenic and fluoride from water is cyclic and regeneration of the alumina media is required periodically. When the alumina columns become saturated with arsenic and fluoride, they are regenerated by passing a caustic soda solution through the media. Excess caustic soda is neutralized by rinsing the activated alumina with an acid. Prior to the regeneration process, the alumina column is backwashed to remove accumulated solids that have been strained from the water. Adequate disposal of the regenerative chemical wash should be provided. One disposal method which warrants consideration is lagoon evaporation. If permitted by local conditions, neutralization of the regenerative chemical wash followed by dilution and discharge to a sanitary sewer should also be considered. Possible toxic effects of the removed arsenic and/or fluoride should be evaluated prior to discharge to a sanitary sewer.

If treated water storage facilities are limited or if interruptions of other treatment plant processes cannot be tolerated, the use of duplicate alumina contact columns is recommended.

b. Activated Carbon. Adsorption of organic impurities using activated carbon has been common practice in the waterworks industry for many years. Activated carbon is especially effective as an adsorbing agent because of its large surface area to mass ratio. Each activated carbon particle contains a tremendous number of pores and crevices into which organic molecules enter and are adsorbed to the activated carbon surface.

Activated carbon has a particularly strong attraction for organic molecules and thus is well-suited for removal of hydrocarbons, control of taste and odor, and color removal. At present, activated carbon has been used with only limited success to remove haloform precursor compounds. Frequent regeneration or replacement of the activated carbon would be required, as its effectiveness in adsorbing precursor compounds is limited to only a few weeks after being placed in use.

Excessive fluoride and un-ionized metals such as arsenic and mercury can be removed from water by adsorption using bone char. However, if used for arsenic removal, bone char cannot be regenerated and must be used on a throw-away basis.

Both the adsorptive and the physical properties of an activated carbon medium are important. Currently, there is no direct method for determining the adsorptive capacity of an activated carbon. Adsorptive capacities can be approximated by the Iodine Number or the Molasses Decolorizing Index. The Iodine Number indicates the capability of the activated carbon for removing small molecules. The Molasses Decolorizing Index provides an indication of the potential of the activated carbon for adsorbing large molecules.

Two types of activated carbon are used in water treatment: powdered and granular. Powdered activated carbon is often used for taste and odor control. Its effectiveness depends on the source of the undesirable tastes and odors. This type of activated carbon is a finely ground, insoluble black powder which can be fed to water either with dry feed machines or as a carbon slurry. Slurry methods are usually applicable only in large water treatment plants, therefore will not be discussed here. The powdered carbon approach offers economic advantages when a low or infrequent carbon usage is required to solve a specific problem.

Powdered carbon may be added at any point in the treatment process ahead of the filters. Actual application points vary depending on local conditions and contaminants to be removed. Normally, application of carbon is most effective where pH of the raw water is lowest. Adequate dispersion of the carbon is necessary; therefore, a settling basin should not be used as a point of application. Sufficient contact time is also necessary to ensure maximum adsorption by the carbon. Periods of contact ranging from 15 minutes to one hour are recommended. Powdered carbon should be applied prior to chlorination. Compounds that have a chlorine demand will be removed by the activated carbon; thus, savings in chlorine will be realized. Also, activated carbon will efficiently adsorb chlorine thus wasting both the carbon and chlorine.

Recent practice recommends the use of carbon for removal of taste and odor producing organics prior to chlorination. This prevents the formation of chloro-organics which are very difficult to remove by carbon. High doses of carbon fed to the filter influent will cause rapid build-up of loss of head and there is the hazard of carbon "bleed-through". Effluents must be carefully monitored when carbon is fed to filter influent.

As a rough guide, dosages for taste and odor control vary from 2 to 8 mg/l for routine continuous application, 5 to 20 mg/l for intermittent severe problems and 20 to 100 mg/l for emergency treatment of chemical spills. Powdered activated carbon has not been recovered and regenerated in the past. Powdered activated carbon either settles out in the clarifier or is retained in the filter. Spent carbon is then disposed of along with other plant waste solids.

Granular activated carbon, used as media in gravity filters, pressure vessels and specially designed adsorbers, is effective for water treatment purposes. Removal of organics and mercury is the primary use of granular activated carbon. Activated carbon filters can be used either in place of, or in addition to, conventional filters.

If activated carbon filters are used in place of conventional filters, special care must be taken in the design and operation of filter cleansing facilities and in the selection of activated carbon granule characteristics so that the filters can be effectively backwashed without the loss of the carbon medium in the backwash troughs.

The use of activated carbon filters has not been widely practiced in the past, so optimum configurations and operating rules have not fully evolved. Many of the guidelines given for conventional filters are also applicable to activated carbon filters.

Filter depths generally vary from 0.8 to 3.0 m (2.5 to 10 ft), with an activated carbon layer of 0.3 to 1.5 m (1 to 5 ft) overlying a layer of coarse gravel above the underdrain system. An intermediate layer of sand, 15 to 46 cm (6 to 18 in) is sometimes used between the activated carbon and the gravel. Flow rates through the activated carbon filters are usually 120 to 300 m^3/m^2/day (2 to 5 gpm/ft^2).

The activated carbon medium must periodically be replaced with new or regenerated activated carbon. Replacement cycles can vary from 1 to 3 years for taste and odor removal down to 3 to 6 weeks for removal of haloform precursors. Regeneration involves (1) removing the spent carbon as a slurry, (2) dewatering the slurry, (3) feeding the carbon into a special furnace where the regeneration occurs, (4) water quenching the carbon, and (5) returning it to use. From 5 to 10 per cent of the carbon is lost during this process. The choice among the alternatives of on-site regeneration, purchase of new activated carbon, or shipment of spent carbon to a regeneration center will be governed by economic considerations.

Furnaces for carbon regeneration can be purchased for on-site use, but the smallest of these has capacity for regenerating 1,360 kg/day (3,000 lb/day) or the carbon requirements at plants having flows of between 38,000 to 76,000 m^3/day (10 to 20 mgd). Therefore, on-site regeneration is not economical for small water facilities. Often located near activated carbon production facilities, regeneration facilities may be too far removed for economical use by a small water treatment plant. If an existing regeneration center cannot be used, construction of a regional facility for activated carbon regeneration should be considered for use by a number of small communities. If drinking water regulations for halogenated organics are established and granular activated carbon is used extensively for precursor or haloform removal, the demand for regeneration facilities will increase.

An alternative to construction, operation and maintenance of an activated carbon filter is use of an "adsorption service". The service consists of a complete modular system furnished to the municipality for a monthly service fee. Delivery of new carbon and removal of exhausted carbon is then the responsibility of the leasing company.

c. **Applicability and Recommendations.** Activated alumina is recommended for removal of arsenic and/or excessive fluoride. Activated carbon can be used for a variety of purposes. Powdered activated carbon is normally used only for taste and odor control or for treatment of color. An economic analysis should be used to determine the applicability of granular activated carbon for removal of foaming agents, mercury, and organic pesticides. Granular activated carbon is usually not economical for treatment of color or tastes and odors.

Replacement or regeneration of spent carbon is of concern when using granular activated carbon. Alternatives available to small water treatment facilities are purchase of new carbon, regeneration of spent carbon at a regeneration center, or use of an adsorption service.

4. Clarification

Coagulation, rapid mixing, flocculation, and sedimentation are the individual processes which make up clarification. Substances producing color and turbidity can be removed by the clarification process. Clarification can also be used in the softening of hard water with lime or lime and soda ash.

Clarification followed by filtration is the most widely used process to remove substances producing turbidity in water. Raw water supplies, especially surface water supplies, often contain suspended substances causing unacceptable levels of turbidity. These include mineral and organic substances and microscopic organisms ranging in size from 0.001 to one micrometer. Particles in this size range are often referred to as "colloidal" particles. Larger particles, such as sand and silt, readily settle out of water during plain sedimentation (without use of chemical coagulation), but settling of colloidal particles using plain sedimentation is not practical. An important characteristic of particles suspended in water is the ratio of particle surface area to mass. For large particles the ratio is relatively low and mass effects, such as sedimentation under the influence of gravity, dominate. On the other hand, particles in the colloidal size range have a relatively large surface area-to-mass ratio and these particles exhibit characteristics dominated by surface phenomena, such as electric charge. Plain sedimentation, on a practical scale, will not remove particles of colloidal dimensions. Coagulation and flocculation processes are required to remove these small particles in sedimentation basins.

a. Coagulation. The terms "coagulation" and "flocculation" are often used interchangeably to describe the overall process of conditioning suspended matter in water so that it can be readily removed by subsequent treatment processes. The coagulation and flocculation processes, though closely related, are distinct and separable and are defined as follows: the term "coagulation" means a reduction in the forces which tend to keep suspended particles apart. The reduction of these repulsive forces allows small particles to join together to form larger particles which settle readily. The joining together of the small particles into larger, settleable and filterable particles is called "flocculation". Thus, coagulation is the precursor of flocculation.

Colloidal particles in suspension in water have electrical charges at their surface. These charges are usually negative. The charge at the surface of the particle causes the particle to attract oppositely charged ions present in the water. The oppositely-charged ions are bound to the outer surface of the particle and form a "layer" around the particle. Thus, if most of the suspended particles in a naturally-occurring water have a layer of positively-charged ions around them, the particles cannot approach each other because of the repulsion between the positively-charged layers of each. The electrical strength at the outer surface of the layer of bound ions is frequently referred to as the "zeta potential". The magnitude of the zeta potential provides an indication of the repulsive forces between suspended particles.

Negation of the repulsive forces between particles is generally achieved by adding salts of trivalent aluminum or iron or a synthetic polyelectrolyte coagulant to the water containing the particles. The aluminum or iron salts cause a series of reactions to occur in the water; the net result of which is reduction of the electrical charges on the particle.

Probably the most frequently used coagulant is aluminum sulfate [approximate formula: $Al_2(SO_4)_3 \cdot 14.3H_2O$], averaging about 17 per cent Al_2O_3, also called "alum" or "filter alum". Other aluminum compounds used as coagulants are potash alum and sodium aluminate, principally the latter. Salts of iron, such as ferric sulfate, ferrous sulfate, chlorinated copperas (chlorinated ferrous sulfate), and ferric chloride are also used as coagulants. Magnesium hydroxide, produced by lime softening of waters high in magnesium, is another effective coagulant. Organic polyelectrolyte compounds have also proven effective as primary coagulants. Certain polyelectrolytes, at low dosage, have been found to significantly enhance the efficiency of turbidity removal in presedimentation basins, and a number of treatment plants now utilize polymers for this purpose.

Determination of type and required quantity of coagulant is usually done through a series of "jar tests". These tests are performed in a laboratory stirrer by applying varying dosages of different coagulants to representative raw water samples. The coagulant is rapidly mixed in the water, and the mixture is then stirred slowly to allow flocculation to take place. Comparison of turbidity removal efficiencies for each of the various coagulants and dosages yields an evaluation of the best coagulant and dosage to be utilized. Inasmuch as mixing times and the quality of the raw water vary, a large number of jar tests are usually required to determine the optimal treatment process.

The pH of the water to be treated often has a significant effect on coagulation. Aluminum salts are most effective as coagulants at pH values from 6.0 to 7.8. For iron salts, the range of pH values at which coagulation may occur is somewhat broader. It is very important that coagulation be carried out within the optimal range of pH values, and, if the pH is not within this range, it may be necessary to adjust the pH.

There are very few definitive rules to follow with respect to coagulation, but the following are useful approximations:

1. Organic turbidity particles are usually more difficult to coagulate than inorganic particles.

2. The required dosage of coagulant does not increase linearly with an increase in turbidity. In fact, very high turbidities often coagulate more easily than low turbidities because of the increased likelihood of particle collisions.

3. If the suspended particles in water are of a wide range of sizes, they are usually much easier to coagulate than if all the particles are of similar size.

Some ions of dissolved salts exert influences on the coagulation processes. Anions exert a much greater effect than cations, and of the common anions found in nature, the sulfate and phosphate ions have the greatest effect on coagulation. Sulfate ions tend to broaden the pH range in which effective coagulation takes place.

In some cases, coagulation can be improved by the use of coagulant aids in addition to the usual aluminum or iron coagulants. The most widely used coagulant aids are activated silica, bentonite clays, and polyelectrolytes.

A partially neutralized sodium silicate solution is known as "activated silica". It is often used as an aid to coagulation because it lowers the required coagulant dose, increases the rate of coagulation, broadens the pH range of effective coagulation, and causes the floc particles to be tougher, which may result in longer filter runs. However, preparation of the sodium silicate solution is difficult, and unless carefully applied, activated silica may actually hinder coagulation and shorten filter runs.

In water containing high color and low turbidity, the floc produced by the addition of the aluminum or iron coagulant is often too light to settle rapidly. Since clays similar to bentonite have a high specific gravity, the addition of particles of bentonitic clays causes the floc to have a higher specific gravity, and it settles more readily. Dosages of bentonitic clays generally range from 10 to 50 mg/l.

There are a large number of commercial polyelectrolytes currently available. Polyelectrolytes are long-chain organic compounds which contain repeating units of small molecular weight. Each of the units has an electrical charge associated with it, which gives the long-chain molecule a large number of similar electrical charges. Polyelectrolytes with negative charges are termed "anionic", while those with positive charges are termed "cationic". Those having essentially no charge are called "nonionic". Polyelectrolytes act as bridging mechanisms between particles in water, and cause small floc particles to agglomerate into large floc particles, with greatly reduced settling times. Anionic and nonionic polyelectrolytes are often used as coagulant aids in conjunction with metal coagulants. Cationic and nonionic polyelectrolytes, used without metal coagulants, have proved effective in reducing turbidity in the first stage of treatment of waters of high turbidity. Optimum dosages of polyelectrolytes, which are usually quite low, must be determined by a series of jar tests.

b. Rapid Mix. In the water treatment plant, coagulation and flocculation are usually effected in two separate mechanical operations. The first operation involves rapid mixing of the coagulant and other chemicals, if needed, including those for pH adjustment and flocculation aid, in a small rapid mix chamber. The purpose of rapid mixing is to uniformly distribute the applied chemicals in the water. The interaction between chemical coagulants and turbidity particles occurs very quickly, so it is essential that the chemical coagulant be rapidly mixed into the water to insure that the coagulation process proceeds uniformly. Generally, rapid mixing is accomplished by creating turbulence with propellers or impellers. As approximate guidelines, the water flowing into a rapid mix chamber usually requires from 20 seconds to two minutes to flow through the chamber, and the mixing units usually need 0.3 to 0.6 W per m^3/day (1 to 2 hp per ft^3/second). In small water treatment facilities, pumps can also be used for mixing.

A useful parameter in the design of rapid mix facilities is the power input into the water, as measured by the velocity gradient G. Rapid mixing is best achieved at G values of 500 sec^{-1} to 1,000 sec^{-1} and detention times of about two minutes, although shorter detention times are often used effectively. Longer detention times for these values of G result in negligible mixing improvement. If high G values ($>$10,000 sec^{-1}) are maintained for as long as two minutes, the subsequent floc formation processes are retarded significantly.

c. **Flocculation**. As previously defined, flocculation is the joining together of small particles into larger, settleable, filterable particles. The primary force of attraction between colloidal particles present in water is the van der Waals force, which is a cohesive force in existence between all atoms. If the repulsive forces between particles, as described under a) *Coagulation*, can be sufficiently reduced to allow van der Waals forces to predominate, the particles will stick together and form larger particles which settle out of the water more readily.

The likelihood of collisions between particles is often enhanced by slow mechanical mixing or agitation ("flocculation") of the water. As more and more particles are joined together, they form flocculent masses which will subsequently settle out of the water. Any particles which are struck by the flocculent material as it settles to the bottom are ensnared in the flocculent mass.

Flocculation, which follows coagulation, is usually accomplished in large tanks with some type of mechanical mixing. The mixing in these basins is intended to promote collisions of the coagulated particles. The motion imparted to the water in the flocculation basins must be much gentler than the motion in the rapid mix chambers; otherwise, the shear forces in the turbulent water would break up agglomerated floc particles. Mixing for flocculation is often accomplished through the motion of a series of paddles rotating either parallel or perpendicular to the direction of flow through the basin. Baffles should be provided between each set of paddles to minimize short circuiting. Walking beam flocculators and vertical axial flow flocculators are commonly used, and can be placed in existing basins.

As in the case of rapid mixing, the value of the velocity gradient G is useful in estimating the effectiveness of mechanical agitation in flocculation basins. The optimal range in values of G appears to be between 20 $\sec^{-1}$ and 70 $\sec^{-1}$. If the velocity gradient is multiplied by the detention time in seconds, an additional parameter GT is obtained. This nondimensional parameter can be used to characterize flocculation basins. Conventional values of GT range from 30,000 to 150,000. Detention times resulting in the best flocculation usually are between 20 and 60 min.

d. **Sedimentation**. After the coagulation and flocculation processes have been completed, the water must pass through a relatively large basin at low velocity to allow the floc particles to settle out. This settling-out process is generally called "sedimentation" or "clarification". The particles removed during this stage of water purification are usually small and not of high density; consequently, large tanks are needed to achieve the quiescent conditions necessary for settling. In the preliminary water treatment process of "plain sedimentation", only the heavier particles, such as grains of sand, are removed from the water, as contrasted to the amorphous floc removed in the post-flocculation sedimentation process.

The most common types of sedimentation basins are the rectangular, horizontal flow and the center-feed, radial flow. In all types of basins, the design objective is to obtain, as nearly as possible, the condition of ideal flow through the basin. Ideal flow for a rectangular basin requires that all of the water entering at one end of the basin should flow in parallel paths of equal velocity to the effluent end of the basin. Ideal flow exists in a circular basin if the centrally-fed water moves in radial paths of equal velocity to the outlet channel of the basin. This ideal flow cannot be attained under actual operating conditions because of imperfect inlet and outlet arrangements, friction, turbulence, short circuiting, etc.

A minimum of two sedimentation basins is usually preferred. However, for many small water treatment plants, two basins are not practical. Use of a single sedimentation basin is recommended only if adequate storage is available to meet water demands while the basin is out of service. If more than one basin is provided, flow division between the basins should be accomplished prior to application of coagulating chemicals. Thus, the plant would have multiple parallel-operating, coagulation, flocculation and sedimentation units.

Rectangular basins vary in width from 1.5 to about 7.3 m (5 to about 24 ft). An approximate width to length ration of 1:4 is common. Basin depths generally range from 2.1 to 4.9 m (7 to 16 ft). Under comparable conditions, deeper basins usually perform better than shallow ones. In general, the basins should be sized to provide an average detention time of 2 to 6 hours. Special conditions may dictate deviation from these general criteria; detention periods in the range of 8 to 12 hours, or more, may be desirable for the treatment of highly turbid waters. If the space available for sedimentation basins is severely limited, the construction of multiple-story basins, in which the water flows horizontally along one level and then passes upward or downward to flow horizontally along another level, may be warranted.

An important parameter in the sizing of sedimentation basins is the "overflow rate", which is defined as the flow rate divided by the surface area of the basin. The overflow rate is usually expressed in terms of m^3/m^2/day (gpd/ft^2). In theory, if the settling velocity of a particle is greater than the overflow rate of the basin and ideal flow exists, the particle will settle out of the water before the water leaves the basin.

Actual sedimentation basins are designed to reduce currents which produce short circuiting and hinder settling. These currents may be the result of inlet or outlet induced turbulence, wind action, density differences, sludge build-up on bottom, etc. The settling rates of alum floc in a conventional sedimentation basin generally range from 0.17 to 0.26 mm/sec, equivalent to overflow rates of 14 to 22 m^3/m^2/day (360 to 550 gpd/ft^2). If the particles to be removed settle more rapidly than alum floc, the area of the basin should be reduced proportionately; and conversely, if the particles settle more slowly, the area of the basin must be increased.

Estimates of suitable overflow rates for sedimentation treatment of water of a given quality can be obtained from cylinder settling tests conducted in the laboratory. The test procedure should approximate full-scale treatment and settling velocity distribution curves showing fraction of turbidity remaining as a function of settling velocity should be developed for each test series.[1]

A large number of carefully conducted tests are required to assess adequately the influence of variations in raw water quality on coagulation, flocculation and settling. For example, water temperature has a significant effect on particle settling rates. If the settling rate of a particle at 30°C (86°F) is 2.2 mm/sec, it would be 1.4 mm/sec at 10°C (50°F) and only about 1.0 mm/sec at 0°C (32°F). The increase in viscosity of the water at lower temperatures greatly reduces settling rates. Settling rate determinations should include tests at the lowest water temperature that will be encountered.

Application of laboratory settling data to actual basin design requires the exercise of considerable judgment. Experience at existing plants treating the same or similar raw water may provide valuable guidance and should be carefully reviewed prior to final decisions on treatment methods, size of basins, etc.

Flocculation-sedimentation basins, usually circular in plan, can be used to combine the functions of flocculation and sedimentation. Flocculation is accomplished in a circular center well. Sedimentation occurs in the annular space between the flocculation section and the perimeter effluent weir.

Suspended solids contact clarifiers combine mixing, coagulation, flocculation, sedimentation, and sludge removal in a single unit. This type of clarifier can be very practical for small systems. Coagulation and flocculation take place in the presence of floc which has been formed previously and cycled back to the primary mixing and reaction zone. This process maintains a high concentration of floc particles and enhances the probability of particle collisions. Settled sludge is removed from the unit continually. The use of these units usually results in a reduction in the space required for treatment facilities, and may result in a cost reduction. Solids contact clarifiers are widely used in connection with lime-soda softening.

A recent development, the "tube" settler, may be used advantageously at some installations, particularly if the capacity of existing sedimentation basins must be increased or if little space is available for the construction of new sedimentation basins. Tube settlers may increase the capacities of sedimentation basins by 50 per cent or more. For more detailed information on tube settlers, refer to section V, Upgrading Existing Facilities.

Water containing the suspended particles is often introduced to the circular basin through a central influent well. The inlet pipe into the influent well is placed either beneath the basin or suspended from a bridge between the influent well and outer wall of the basin. The water is discharged from the influent well into the circular basin, where it flows radially outward toward outlet troughs along the perimeter of the basin. As in the case of rectangular basins, the water inlet must be designed so as to minimize turbulence in the influent flow. A cylindrical baffle at the center of the basin is the most common type of influent well in use. The outflow from circular basins is generally collected in an outflow channel which follows all or most of the periphery of the basin.

Peripheral-feed, circular tanks are also employed. Water is distributed around the tank perimeter and flows radially toward effluent collection facilities located in the center.

1. Inlet Arrangements. Inasmuch as the effectiveness of sedimentation basins is dependent on the degree of attainment of uniform, quiescent flow, it is essential that the water entering the basin be distributed to minimize turbulence or intertial currents. Also, the velocities of the water in the pipeline or flume carrying water to the sedimentation basin must be about 0.15 to 0.6 m/s (0.5 to 2.0 ft/s). Lower velocities will result in deposition of the floc and sediment in the pipe or flume; higher velocities may cause breakup of the flocculated particles.

Where inlet pipelines or flumes are used, the conventional methods of uniformly distributing the water at the influent end of the basin are through horizontal or vertical slots in a baffle wall, or through a series of orifices in an inlet chamber. The efficiency of most sedimentation basins is highly dependent on the design of the inlet arrangement.

2. Outlet Arrangements. V-notch weir plates are often used for basin outlets, and these should be installed with provisions for vertical adjustment to insure uniform flow along the length of the weir. Weir rates commonly vary from 140 to about 270 m^3/day/m (8 to about 15 gpm/ft), with the higher values for heavier floc, such as that derived from lime softening. Submerged orifices are also used for basin outlets. Advantages of this type of outlet over the V-notch weirs include: (1) climatic effects of wind and ice are reduced and (2) volume above the orifices is available for storage while filter is backwashed. The recommended maximum velocity through submerged orifices is 0.6m/s (2 ft/s). Higher velocities may cause currents which inhibit settling or break up the flocculated particles.

3. Sludge Removal. The solids which settle to the bottom of the sedimentation basin are called "sludge". This sludge must be removed from the bottom of the basin before the depth of the sludge becomes great enough to interfere with effective sedimentation. If the sludge layer becomes too thick, the effective volume of the basin is decreased resulting in an increase in the velocity of the water flowing through the basin. The higher velocity of water in the basin increases the friction between the sludge layer and the water, with the result that sludge particles are resuspended and enter the outflow from the basin.

Settled sludge can be removed in either of two ways: (1) by taking the sedimentation basin out of service periodically for cleaning, usually by flushing, or (2) by mechanical sludge collectors which consist of slow-moving, mechanically-driven scrapers. Almost all sedimentation basins are now cleaned by mechanical devices rather than by taking them out of service. Sludge scrapers force the sludge into hoppers located at the influent end of the rectangular sedimentation basins. The sludge is drawn off from the hoppers and discharged to a point of disposal. These scrapers must move at low velocity so as to avoid interfering with the settling process. The bottoms of rectangular sedimentation basins are sloped toward the sludge hoppers to facilitate the action of the mechanical sludge collectors. The most common slope used is 1:100 (vertical: horizontal).

e. Softening. Water softening is the process of reducing hardness. Hardness is caused principally by calcium and magnesium ions in water. Softening of the entire supply is usually justified when total hardness exceeds 300 mg/l and may prove economically advantageous at hardness levels above 200 mg/l.

Two general types of processes are used for softening. These are the lime-soda ash process and the cation ion exchange process, often called the zeolite process. The lime-soda ash process is used principally at water treatment plants serving a fairly large population. The cation exchange process can be similarly applied and, in addition, is adaptable to small water treatment facilities.

Equipment, basins, and filters required for lime softening are generally similar to the facilities used in conventional coagulation-filtration plants. In fact, many filtration plants, not originally designed for softening, have been converted to softening plants by the installation of necessary facilities.

Many lime softening plants, particularly those treating ground water, use solids contact type basins. These basins provide the functions of mixing, sludge recirculation, sedimentation and sludge collection in a single unit. Basins of this type, if properly sized, will provide effective softening and clarification treatment.

A disadvantage of any lime softening process is the production of a large volume of sludge of high water content. Provision for sludge disposal in an environmentally acceptable manner must be considered in designing a lime softening plant.

Cation exchange or "zeolite" softening is accomplished by exchanging calcium and magnesium ions for a cation, usually sodium, which does not contribute to hardness. Basically, this exchange consists of passage of water through a bed of granular sodium cation media. The calcium and magnesium in the water react with the media and are replaced with an equivalent amount of sodium. This reaction is reversible and the exchanger can be regenerated with a strong solution of sodium chloride (common salt). Disposal of backwash water, brine waste and rinse water must be carefully considered. As water with an increased sodium content is produced by cation exchange softening, this process may not be desirable for individuals on low sodium diets. Softening of hard water using the ion exchange process is discussed in detail in section IV 8.

f. Applicability and Recommendations. Clarification facilities are readily adaptable to small water treatment systems. Rapid mix, coagulation, flocculation and sedimentation are recommended for removal of turbidity and color. Also, laboratory tests have indicated clarification, followed by filtration, effective in removing the following contaminants: arsenic, cadmium, chromium, lead, mercury, selenium, silver, radium, endrin and 2,4,5-TP (Silvex). Also an aid in reducing the bacteria level, clarification should not be used in place of disinfection. Before the clarification process is selected for treatment of any contaminant other than turbidity or color, operational tests with full-size equipment should be performed.

For design of rapid mix facilities, a detention time of 20 to 30 seconds and a velocity gradient, G, of 1,000 is recommended. An alternative to the conventional rapid mix chamber is the use of pumps for mixing. However, a disadvantage of using pumps is that the mixing cannot be controlled.

The minimum detention time recommended for a flocculation basin is 20 to 45 minutes, depending on the material to be flocculated. Vertical axial flow turbines are appropriate for the majority of small water treatment systems. Paddle reel flocculators parallel to the flow should be compared to vertical axial flow turbines for use in all but the smallest treatment plants.

Two settling basins are recommended as a minimum for most treatment facilities. Very small systems such as those using package plants, however, may use a single sedimentation basin if storage is provided. Flocculation–sedimentation basins are appropriate for use in small water treatment plants as are tube settlers. Settling tubes are most commonly used in package water treatment plants and in modification of existing facilities.

Cation exchange or "zeolite" softening is well-suited for use in small water treatment systems. In addition to hardness reduction, cation exchange softening is also an effective method for radionuclide reduction. Lime softening is not recommended for small water treatment facilities unless an analysis indicates it to be economically desirable compared to ion exchange softening. Laboratory tests have indicated lime softening effective in removing arsenic, barium, cadmium, chromium, fluoride, lead, mercury, selenium, silver, radioactive contaminants, copper, iron, manganese, zinc and, to a certain degree, TDS.

5. Filtration

Filtration of water is defined as the separation of colloidal and larger particles from water by passage through a porous medium, usually sand or granular coal. As water passes through the medium, the suspended particles in the water are either left in the interstices between the grains of the medium or left on the medium itself. Sand filtration will remove particles much smaller than the void spaces between the sand grains. This phenomenon is probably due principally to the fact that a bed of sand or other similar granular material possesses a huge surface area, much of which is in contact with the water and the particles suspended in it. The particles are attracted to the surface of the granular medium and are held there by relatively strong surface forces. These surface forces are apparently large enough to attract and bind particles to the medium surface even though the particles may bear the same electrical charge as the filter grains. The suspended particles removed during filtration range in diameter from about 0.001 to 50 micrometers and larger.

Water filters can be classified in various ways. They may be identified hydraulically as slow or rapid, depending upon the rate of flow per unit of surface area. Filters are also classed according to the kind or type of filter media employed, such as sand, anthracite coal, coal-sand, multilayered, mixed bed, or diatomaceous earth. They may be described according to the direction of flow through the bed, that is downflow, upflow, biflow, fine-to-coarse, or coarse-to-fine.

Filters are also commonly distinguished between pressure and gravity (or free surface) filters.

a. **Gravity Filters.** Gravity filters are free surface filters and as their name would imply, are used for filtering water under gravity flow conditions. Gravity filters are distinguished from pressure filters and are much more commonly used for municipal applications. The various media types previously discussed may be used in gravity or pressure filters. Gravity filters are typically characterized by downflow operation followed by an upflow washing of the filter media to remove the foreign material collected in the bed.

b. **Pressure Filters.** Pressure filters are very similar in filter bed construction to a typical gravity filter; however, in a pressure filter the entire filter apparatus, including media layer, gravel bed, and underdrains, is enclosed in a steel shell. An advantage of a pressure filter is that any pressure in the water lines leading to the filter is not lost, as in the case of gravity filters, but can be used for distribution of the water once it has passed through the pressure filter. About 0.9 to 3 m (3 to 10 ft) of pressure head is lost in friction through the filter bed, but any pressure in excess of this can be utilized for water distribution.

A disadvantage of pressure filters is the potential loss of media during backwash which cannot be observed.

c. **Diatomite Filters.** A special type filter which is usually operated under pressure is the diatomite filter. It consists of a layer of diatomaceous earth supported by a septum or filter element. This layer of diatomaceous earth is about 3.2 mm (1/8 in) thick at the beginning of filtration and must be maintained during filtration by a constant body feed of diatomite filter medium to the influent unfiltered water. At the conclusion of a filter run, the layer of diatomaceous earth will have increased in thickness to about 13 mm (1/2 inch). Filtration rates generally vary from 30 to 120 m^3/m^2/day (0.5 to 2.0 gpm/ft). The chief difficulty in using diatomite filters is in maintaining the diatomaceous earth film of uniform permeability and filtering capability. Applicable methods for disposal of diatomaceous earth filter sludge include use of a lagoon or landfill.

d. Media.

1. Single Media. Single media filters are those which employ only one type of filtering medium as opposed to dual and mixed media filters. Types of single media filters include rapid sand, slow sand, and anthracite. The vast majority of present-day water plants use single media filters with the most common type being rapid sand filters.

Rapid Sand Filters. Rapid sand filters are those filters which commonly operate at rates of about 120 to 240 m^3/m^2/day (2 to 4 gpm/ft^2). A "standard" rate for rapid sand filtration of surface waters is 120 m^3/m^2/day (2 gpm/ft^2) while ground waters are usually filtered at 180 to 240 m^3/m^2/day (3 to 4 gpm/ft^2). If higher rates are to be used in design, great care must be taken to insure that all prefiltration treatment processes including coagulation, flocculation and sedimentation will perform satisfactorily and consistently. High rate filter operation requires excellence in prefiltration treatment.

The filter medium, which has traditionally been silica sand, is generally supported on a gravel bed. Beneath the gravel bed lies an underdrain system which collects the filtered water. The filter sand layer is generally about 64 to

76 cm (25 to 30 in) thick and the supporting gravel bed is usually 30 to 46 cm (12 to 18 in) thick. Head loss through a clean filter is about 0.3 m (1 ft) and the filter is cleaned by backwashing when the head loss reaches about 2.4 m (8 ft).

The filter sand usually has an effective size of 0.35 to 0.50 mm and a uniformity coefficient of 1.3 to 1.7. The "effective size" of a sample of sand is a grain diameter such that 10 per cent by weight of the sample has smaller diameters. The "uniformity coefficient" is the ratio of the grain diameter with 60 per cent of the sample smaller to the grain diameter with 10 per cent of the sample smaller. A sand to be used as a filter medium is tested by sieve analysis to determine the gradation of grain sizes in the sand. Sand finer than about 0.3 mm stratifies at, or near, the surface of the filter, thereby shortening the filter runs. Sand coarser than 1.2 mm is generally too large to effect good removal of suspended matter. Filter sand should be clean and have a specific gravity of not less than 2.5. For filtration of low pH water, the sand should not lose more than 5 per cent by weight when placed in hydrochloric acid. Filter sands for use in water softening plants are somewhat coarser than those indicated above. For detailed specifications for filtering material, reference should be made to "AWWA Standard for Filtering Material", AWWA B100-72, as published by the American Water Works Association.

The gravel bed beneath the filter sand is designed to keep the sand from passing into the underdrains and also to distribute the wash water uniformly during backwashing. Ideally, the gravel bed should be composed of well rounded gravel, with a uniform variation in diameter from the top of the bed to the bottom, ranging from about 1.6 mm (1/16 in) at the top to about 25 mm (1 in) at the bottom. It is important for the gravel to have few irregularly shaped (thin, flat, jagged) stones and to be essentially free of soil, sand, or organic residue of any kind.

The filter underdrains are placed at the bottom of the gravel bed and serve a dual purpose: (1) to collect the filtered water, and (2) to distribute backwash water uniformly beneath the filter sand and gravel bed. Types of underdrains include perforated pipe-grids and false bottom systems of various types. Perforated pipe-grid underdrain systems have been used; however, the false bottom systems are preferred.

Porous plate or porous block false bottoms are suitable where deposition within the pores of the plates or blocks is not a problem. If deposition occurs, the plates or blocks must be cleaned promptly as otherwise there will be a progressive, undesirable increase in head loss across the plates. Structural failure may occur during backwashing if clogging is severe. Some false bottom systems employ vitrified clay blocks containing orifices; others are constructed of concrete and contain orifices terminating in inverted square pyramids filled with large and small earthenware spheres. A variety of underdrains of the false-bottom type have been developed and used successfully.

Slow Sand Filters. Slow sand filters have a similar configuration to rapid sand filters with a bed of sand supported by a layer of gravel. The filtration rate for slow sand filters ranges from 2.9 to 5.9 m^3/m^2/day (0.05 to 0.10 gpm/ft^2) thus requiring large land areas. For this reason, slow sand filters have not been constructed in the United States in recent years.

Anthracite Filters. Anthracite coal is another filter medium which is used in single media filters. Coal has a lower specific gravity than sand and has greater bed porosity for a given effective size. The layer of anthracite coal media used in a filter should be about 60 to 76 cm (24 to 30 in) deep with an effective size less than 1.2 mm. The specific gravity of the coal should be at least 1.5, since coal particles with lower specific gravities will often be carried away in the backwash water, even at minimal rates of backwash flow. Operating rates for anthracite coal filters usually range from about 120 to 240 m^3/m^2/day (2 to 4 gpm/ft^2).

Activated Carbon Filters. Granular activated carbon may be used as a filter medium for removal of taste and odor causing organics. Commonly a layer or bed of activated carbon will be placed on top of the conventional filter bed rather than completely replacing it. A further, more complete discussion of activated carbon and its uses is included in section IV 3b.

2. Dual Media. Dual media filters are those employing two types of filtering media usually arranged in a coarse to fine configuration with coarse media on top. An anthracite coal-sand arrangement is the most common type of dual media combination. Typically, coal-sand filters consist of a coarse layer of coal about 46 cm (18 in) deep above a fine layer of sand about 20 cm (8 in) deep. Some mixing of coal and sand at their interface is desirable to avoid excessive accumulation of floc at this point. This intermixing also reduces the void size in the lower coal layer causing it to remove floc which otherwise might pass through. The coarse to fine media arrangement has an advantage over a single media filter because the effective depth of the filter bed is increased as is the length of filter runs.

In a conventional rapid sand filter with a single sand layer that has been hydraulically classified by backwashing, the smallest sand grains will be near the top of the bed. Any suspended matter that passes through the top few inches of sand may pass through the entire filter bed. Thus, the effective depth of a traditional rapid sand filter is only a few inches. However, when a coarse medium is placed over a fine medium the filtration ability of the unit is increased, since the larger particles in the water will be removed in the coarse medium and the smaller particles will be removed in the fine medium. Flow rates for dual media filters can thus be increased to about 240 m^3/m^2/day (4 gpm/ft^2).

3. Mixed Media. Mixed media filters are those filters employing more than two types of filtering media arranged in a coarse to fine configuration. Typically, the mixed media bed consists of three layers: coal with specific gravity of 1.4 on top, sand with specific gravity of 2.65 in the middle, and garnet with specific gravity of 4.2 on the bottom. They are normally used in the proportions of about 60% coal, 30% sand, and 10% garnet by volume. After backwashing, the three materials become mixed thoroughly throughout the depth of the bed. The top of the bed is predominantly coal, the middle is predominantly sand, and the bottom is mostly garnet, but all three are present at all depths. In a properly designed mixed media bed, the pore space and the average grain size decrease uniformly from top to bottom. Just as in single and dual media filters, the bed is underlain by a layer of supporting gravel.

The vast surface area of the filtering media greatly increases the length of filter runs. The total surface area of the grains in a mixed media bed is much greater than for a sand or dual media bed, which makes it much more resistant to breakthrough and more tolerant to surges in flow rates. One of the primary benefits of the mixed media bed is an improved finished water quality.

e. **Backwashing Facilities.** Filter backwashing involves washing the filter media to remove the material that has been filtered from the water. This material consists of particles trapped in pore spaces as well as on the surface of the filter media. Backwash water is applied to the underside of the filter bed through the underdrains, which should be designed to provide an even application of wash water to the filter. The wash water containing the material removed from the filter medium is carried away in wash water troughs, located above the surface of the filter medium. Backwashing is necessary whenever the head loss through the filter exceeds the acceptable value, usually about 2.4 m (8 ft), or when effluent turbidities are unacceptably high.

The water used for washing the filters should be obtained from protected storage and can be gravity or pumped flow. As a minimum, sufficient wash water should be available to allow backwashing of any filter at up to 1200 m^3/m^2/day (20 gpm/ft^2) for 10 minutes. Installation of standby backwash pumps should be considered to insure reliability. The need for backwash pumps can be eliminated by construction of an adequately sized wash water tank at an elevation sufficient to provide the required flow. The choice between elevated storage tanks and the use of backwash pumps must be made on a case-to-case basis. Wash water tanks are usually filled by small pumps automatically controlled by the water level in the wash water tank. The amount of wash water required will generally average about one per cent of the water filtered and should not exceed five per cent.

In addition to the backwash facilities, some filters are also installed with surface wash facilities. Filter agitation would better describe its function as the surface wash aids in cleaning much more than the filter surface.

The backwash process does not always wash away all waste material and mud balls can form from the agglomerated waste within the filter and on the surface of the filter media. These mud balls can eventually become large enough to clog portions of the filter. An adequate surface wash will prevent mud ball formation because it aids in agitation of the entire filter bed during the backwash process.

Rotary washers are the most common type of surface wash equipment; however, fixed jets are also used. The surface wash system usually consists of horizontal pipes containing a series of nozzles. The horizontal pipes are connected by vertical pipes to water lines above the filters. The nozzles have small orifices through which water is forced down onto the filter surface. Surface washers are usually started in advance of the normal backwash flow and are turned off just before the end of the backwash period. Surface wash systems are commonly used with all types of filters, but are especially necessary for dual and mixed media filters to obtain adequate cleaning deep within the bed.

f. Filtration Aids. In order to improve the filtrability of the water and to permit higher filtration rates, it is often advantageous to add a polyelectrolyte to the settled water prior to its passage through the filter. Polyelectrolytes, also known as polymers, are high molecular weight, water soluble compounds which can be used as primary coagulants, settling aids, or filtration aids. A filtration aid will increase the strength of the chemical floc and aid in controlling the depth of penetration of floc into the filter. It is usually added directly to the filter influent and the dosage required is normally less than 0.1 mg/l.

The use of a filtration aid is usually warranted only for coarse-to-fine filters which includes dual media and mixed media filters. Conventional fine-to-coarse rapid sand filters are rapidly sealed off at the surface when filtration aids are used.

g. Applicability and Recommendations. As discussed in section IV4, Clarification, filtration after clarification is used in the removal of numerous contaminants. Rapid sand filters are an acceptable means of water filtration for most requirements and are quite commonly used today. Dual and mixed media filters are not as widely used, but are capable of producing an effluent of higher quality.

Dual media filters, usually of the coal-sand variety, can be operated at higher rates than rapid sand filters with an increase in length of filter runs. Mixed media filters are an improvement over dual media filters allowing for operation at even higher rates with longer filter runs. The variations in filter media only slightly affect the cost of the total filter. A surface wash system should also be installed in the mixed media filter to aid in backwashing.

Activated carbon filters are to be considered as a method of removing taste and odor causing organics from water. As discussed in section IV A 3b, they may be used in place of, or in addition to, conventional filters. The use of separate activated carbon beds will be more expensive, but is preferred.

In general, gravity filters are more commonly used than pressure filters in municipal applications although either is an acceptable means of filtration. The major disadvantages of pressure filters are that they are completely enclosed within a steel shell. Thus, access to the filter bed for normal observation and maintenance is restricted. The steel shells also require careful periodic maintenance to prevent internal and external corrosion. However, for small systems, the use of pressure filters as opposed to gravity filters is often advantageous. Initial investment cost savings may be realized and if the pressure requirements and conditions in a particular system are such that finished water pumping can be reduced or eliminated through the use of pressure filters, additional cost savings may be realized.

6. Disinfection

As currently practiced in the water treatment industry, disinfection involves destruction or deactivation of objectionable organisms. These organisms may be objectionable from the standpoint of either health or aesthetics. They consist of certain classes of bacteria, viruses, protozoa, and some larger organisms. Inasmuch as the health of water consumers is of major concern to those responsible for supplying water, design of facilities for disinfection must necessarily be carefully executed.

Chlorination, including the use of chlorine dioxide, and ozonation are the most frequently used methods of disinfection for potable water treatment. Other means of disinfection have been attempted with varying degrees of success. These include treatment with reverse osmosis, ultra-violet light, heating of water, addition of elements similar to chlorine such as bromine or iodine, and addition of metal ions such as silver. None has achieved significant acceptance by the water supply industry.

a. **Chlorine.** The application of various forms of chlorine to water in order to effect disinfection has come into such common acceptance that "chlorination" and "disinfection" are almost considered synonymous. Other modes of disinfection generally lack the persistence of chlorine or are more costly to use than chlorine.

Terms frequently used in connection with chlorination practice are defined as follows:

> *Chlorine Demand.* The difference between the concentration of chlorine added to the water and the concentration of chlorine remaining at the end of a specified contact period is defined as chlorine demand. Chlorine demand varies with the water quality, concentration of chlorine applied, time of contact, and temperature.
>
> *Chlorine Residual.* The total concentration of chlorine remaining in the water at the end of a specified contact period is defined as chlorine residual. Two types of residuals are encountered in chlorination practice. They are designated: "combined available residual chlorine" and "free available residual chlorine". They are frequently referred to simply as "combined residual" and "free residual".

Chlorine is applied to water in one of three forms: as elemental chlorine, as hypochlorite salts or as chlorine dioxide. The use of hypochlorites and chlorine dioxide as disinfectants is discussed in subsequent sections.

Elemental chlorine added to water forms hypochlorous acid ($HOCl$) and hydrochloric acid (HCl) according to the following reaction:

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \qquad (6\text{-}1)$$

This equation is usually displaced to the right and very little Cl_2 remains in solution. Immediately after the above reaction takes place, the hypochlorous acid ($HOCl$) dissociates into hydrogen and hypochlorite ions, as indicated in this equation:

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad (6\text{-}2)$$

The degree of ionization is dependent on the pH of the water. At a pH of 6.5, approximately 90 per cent of the hypochlorous acid is not dissociated. If the pH is raised to 8.5, about 90 per cent of the hypochlorous acid will have dissociated to hydrogen and hypochlorite ions, as indicated in equation 6-2. Between pH 6.5 and 8.5, any chlorine present in the water exists as both hypochlorous acid and hypochlorite ions. Chlorine existing in water in these two forms is defined as "free available chlorine".

As shown in equations 6-1 and 6-2, the addition of elemental chlorine to water results in an increase in the number of hydrogen ions (H^+) in solution. This means that the pH of the water is decreased, and treatment for pH correction may be required if high concentrations of chlorine are applied.

1. Reactions of Chlorine With Ammonia. If chlorine is added to water containing ammonia, the ammonia and the hypochlorous acid react to form compounds known as chloramines. Chlorine will also react with compounds containing both carbon and nitrogen to form organic chloramines. The relative amounts of the different chloramines formed are dependent on pH, time, temperature and the quantities of chlorine and ammonia initially present in the water. Formation of chloramines greatly reduces the reactivity of the chlorine and hence longer detention time is required to achieve the same disinfection.

Any chlorine in water which has combined with nitrogen, whether ammonia nitrogen or organic nitrogen, is known as "combined available chlorine." It is emphasized that the disinfecting power of combined available chlorine is of a low order compared with free available chlorine.

2. Reactions of Chlorine with Other Substances. In addition to the reactions with water and nitrogenous substances, chlorine also enters into reactions with other materials present in water. Inasmuch as the oxidizing power of free available chlorine is high, typical inorganic reducing agents such as hydrogen sulfide, ferrous iron, and divalent manganese are rapidly oxidized in the presence of chlorine. Chlorine also oxidizes nitrites to nitrates. Organic materials present in the water will also react with chlorine. The reactions between chlorine and organic substances may involve oxidation, substitution and addition. A multiplicity of chloro-organic compounds is possible. Some, such as chlorophenol, have been identified and are known to cause objectionable tastes when present in trace amounts. The extent and nature of chlorine's many possible reactions with dissolved organics are not well defined; but it is known that trihalomethanes are widespread in chlorinated drinking waters and they result from chlorination. In general, total trihalomethane concentrations are related to the organic content of the water and chlorine dosage. At present, a maximum contaminant level for trihalomethanes has not been established by EPA. However, if a source of low organic content is not available, special treatment processes that will reduce the organic concentration prior to chlorination should be investigated. Chlorine should be applied only after processes which will reduce the organic concentration and thus decrease the chance of trihalomethane formation.

3. Disinfection Properties of Various Forms of Chlorine. The means by which chlorine destroys various types of organisms are not known precisely. It is suspected that the chlorine penetrates cells of microorganisms and disrupts vital enzyme activities. Various studies have shown that, of the various forms of chlorine, hypochlorous acid (HOCl) is by far the most powerful disinfectant. The hypochlorite ion (OCl^-) is far less effective. Also, the disinfecting power of combined available chlorine (chloramine) is much less than that of free available chlorine. In general, *about 25 to 100 times as much combined available chlorine* as free available chlorine is required to achieve equal degrees of disinfection in the same time period. The fact that combined chlorine persists for a long time in water is often viewed as advantageous from a water safety standpoint. This persistence is an indication of low reactivity of chloramine, a distinct disadvantage insofar as the disinfection rate is concerned. However, chloramine residuals can be used to provide long-lasting residual in potable water distribution systems.

4. Chlorine Dosages. Chlorination is used to eliminate or inactivate most water-borne pathogens. Those pathogens that are regarded as the most significant in water are bacteria, amoebic cysts, and viruses. The efficacy of chlorination in achieving the desired destruction or deactivation of these three types of pathogens is strongly dependent on four factors: contact time, pH, temperature, and the type of chlorination used; i.e., free residual chlorination or combined residual chlorination. As previously indicated, free residual chlorination is far more effective than combined residual chlorination. Chlorine disinfection processes are enhanced by low pH, high temperature, and long contact time.

The effectiveness of bacterial disinfection can be checked by bacteriological tests for the presence of organisms of the coliform group. Pathogens, such as typhoid bacteria *(Salmonella typhosa)* are known to be at least as vulnerable to chlorine as coliform bacteria. Therefore, coliforms, which are easily detected by bacteriological methods, serve as indicator organisms for water safety. On the other hand, coliform tests may not be indicative of parasitic protozoa, such as *Entamoeba Hystolytica,* the causative agent of amoebic dysentery. The cysts of this organism are far more resistant to chlorine than coliform bacteria and chlorination alone cannot be assumed to provide an ample margin of safety unless relatively high concentrations of free available chlorine are employed. Free chlorine residuals required to destroy amoebic cysts (cysticidal residuals) are higher than those usually employed by water utilities. However, other treatment processes (coagulation, flocculation, sedimentation, filtration) are effective in removing amoebic cysts and should always be employed in conjunction with chlorination when treating surface waters derived from uncontrolled watersheds.

Disease-producing viruses must be assumed to be present in waters that are subject to sewage pollution. In general, viruses are more resistant to chlorine than coliform organisms and other enteric bacteria. Therefore, negative coliform results may not be indicative of virus destruction. The matter of virus removal or inactivation by water treatment systems needs, and is now receiving, intensive study. Currently, it is known that, of all the forms of aqueous chlorine, only un-ionized hypochlorous acid (HOC1) is an effective agent for virus destruction. A hypochlorous acid concentration of 1.0 mg/i will provide viral inactivation within 30 minutes. Therefore, free residual chlorination at pH values somewhat below about 7.5 is indicated for effective virus disinfection. At pH values of 7.5, or lower, about 50 per cent or more of the free available chlorine will be present as hypochlorous acid (HOC1). As in the case of amoebic cysts, other treatment processes, such as coagulation and filtration, assist in virus removal.

5. Application of Chlorine. Chlorine may be applied to water in a variety of locations in the water treatment plant, storage facilities, or distribution system and in any of several different chemical forms, as discussed previously. Chlorine should be applied at a point which will generally provide a contact time of 15 to 30 minutes. A key feature of chlorine application is thorough mixing. It is absolutely essential that the chlorine applied to the water be quickly and thoroughly mixed with the water undergoing treatment. If required, special chlorine mixing facilities should be provided. In some systems using raw waters of exceptional bacteriological purity, chlorination is the only treatment the water receives (all public water supplies should receive disinfection as a minimum treatment). This is the case with many ground water supplies, as chlorine is often added to the pipeline just beyond the well pumps. In conventional water treatment plants, chlorine may be applied prior to any other treatment process (prechlorination), following one or more of the unit treatment processes (postchlorination), or in the more distant points of the distribution system (rechlorination). Prechlorination is often used because the water contains a chlorine residual for the entire treatment period, thus lengthening the contact time. The coagulation, flocculation, and filtration processes are often improved by prechlorination of the water, and nuisance algae growths in settling basins are reduced. However, prechlorination is not universally recommended. Chlorine should be applied after processes which will remove haloform precursors, such as coagulation and sedimentation or granular activated carbon adsorption. Haloform precursors are much easier to remove from water than haloforms.

6. *Chlorination Equipment.* Elemental chlorine can be injected into water with either of two types of chlorine feeders: the direct-feed type and solution-feed type. Solution feeders are preferable to direct-feed devices because of increased safety and ease of control of chlorine feed rates. Chlorination systems can be controlled either manually or automatically. For small water treatment facilities, manual control is usually adequate. If automatic controls are used, provision for manual control during emergency situations should be included.

7. *Precautions in the Use of Chlorine.* The presence of chlorine gas in the atmosphere of a water treatment plant can pose immediate and serious health hazards. Adequate ventilation of areas where chlorine gas is to be stored or handled is a prime safety precaution. Safety equipment such as gas masks or chlorine detectors must be provided. Chlorine storage and feed facilities should have outside access only. Safety recommendations are given in the American Water Works Association's publication "Safety Practice for Water Utilities".

Valuable data on the properties of chlorine and its safe handling are also available from the Chlorine Institute.

b. Hypochlorites. Hypochlorites are classified as either dry or liquid according to commercial availability. Calcium hypochlorite is the predominant dry bleach in use today; sodium hypochlorite is the only liquid hypochlorite disinfectant in general use.

Commercial high-test calcium hypochlorite products (HTH) contain at least 70 per cent available chlorine. Calcium hypochlorite is an off-white material and is available in granular or tablet forms. Although a highly active oxidizer, calcium hypochlorite is relatively stable throughout its production, distribution and storage. Under normal storage conditions, about 3 to 5 per cent of the available chlorine content is lost in a year. Calcium hypochlorite should be kept in shipping containers and stored in clean, dry, cool areas. Containers should be arranged so that they can be easily moved in event of leaks.

Readily soluble in water, tablet forms of calcium hypochlorite dissolve more slowly than granular materials and provide a steady source of available chlorine over an 18 to 24 hour period. Calcium hypochlorite may be applied either in dry or solution form.

Commercial sodium hypochlorite is manufacturered by numerous companies and is often referred to as liquid bleach. It usually contains 5 to 15 per cent available chlorine and is available only in liquid form. Sodium hypochlorite solutions deteriorate more rapidly than calcium hypochlorite. Storage should be in a cool dark place and a maximum shelf life of 60 to 90 days is recommended by most manufacturers.

Sodium hypochlorite is less expensive than calcium hypochlorite. This lower chemical purchase cost may be offset by increased storage and handling problems. An alternative to purchase of sodium hypochlorite is use of a system for on-site generation of this disinfectant. Raw materials required are salt, either in a brine solution or seawater, power and water. Both the salt and water must be as hardness free as possible to prevent precipitates from fouling the system. If sodium hypochlorite is to be used for disinfection, an economic analysis should be used to determine whether it should be purchased or generated on-site.

Any hypochlorite solution used in the disinfection process must be pumped through an injection system into the water to be chlorinated. This pumping can be accomplished by a diaphragm pump driven by an electric motor.

c. **Chlorine Dioxide.** Chlorine dioxide has disinfection properties approximately equal to those of chlorine. Unstable enough to require on-site generation, chlorine dioxide is more expensive than chlorine. At this date, there is no satisfactory test for residual chlorine dioxide. Rarely applied solely for the purpose of disinfection, chlorine dioxide is used principally in connection with taste and odor control.

d. **Ozone.** Ozone is produced by the passage of dry air or oxygen between two high-voltage electrodes. Electric discharges through the air or oxygen between the electrodes result in the formation of ozone. For small sytems, air feed facilities are the most practical. Like chlorine, ozone is a toxic substance. Ozone molecules contain three atoms of oxygen and are highly reactive. Ozone cannot be stored as a compressed gas; it must be generated at the point of use and used as soon as generated. Advantages of ozone include:

1. Rapid and effective disinfecting action. Ozonation is effective against amoebic cysts, and bactericidal efficiencies are at least as high as those obtained with chlorination.

2. Taste, odor, and color problems are largely reduced or eliminated.

3. Temperature and pH variations have little effect on the disinfecting capability of ozone, except that at high water temperatures it becomes more difficult to dissolve the ozone in water.

Disadvantages of ozonation include:

1. Large quantities of electric energy are required, about 22 to 26 kWh per kg (10 to 12 kWh per pound) of ozone for air feed systems. Better efficiency, 4.4 to 8.8 kWh per kg (2 to 4 kWh per pound), is obtained when oxygen feed systems are employed.

2. Unlike chlorine, ozone provides no residual disinfection capability. Residual ozone reverts rapidly to oxygen.

3. Ozone production facilities must be designed to meet the maximum rate of use because ozone cannot be stored.

4. The equipment required to generate the ozone and inject the large volume of ozonized air into the water is expensive.

5. Because of the high energy requirements and complexity of ozonation systems, the probability of system shutdown is higher than with chlorination systems; consequently chlorination systems are often installed for standby use.

Ozone is being investigated as an alternative disinfectant to chlorine because chlorine is implicated in the formation of haloforms. The use of ozone avoids the formation of compounds such as chloroform, but the reaction products of ozone have not been identified. Currently, chlorination is to be preferred over ozonation as a means of disinfection for most water systems. Ozonation facilities should not be planned at small water treatment plants unless unusual conditions, which preclude use of chlorination, are encountered.

e. **Applicability and Recommendations.** Disinfection is used for bacteria reduction. For small water treatment facilities, chlorine, calcium hypochlorite and sodium hypochlorite are the most applicable chemicals for disinfection purposes. Choice of a specific disinfectant should be based on an economic analysis. Chlorine is usually the most economical disinfectant for treatment facilities with a capacity of 2800 m^3/day (0.75 mgd) and larger. In general, the required chlorine dosage will vary from 1 to 10 mg/l for contact times of from 15 to 30 minutes. Selection of a specific dosage and contact time should be based on the treatment objective, i.e., disinfection, taste and odor control, etc. Chlorine solution feeders are recommended for feeding chlorine gas to water.

Hypochlorite will be the most economical disinfectant for the majority of small water treatment systems. In general, it will be the disinfectant of choice for treatment facilities with a capacity less than 2800 m^3/day (0.75 mgd). The decision to use calcium or sodium hypochlorite should be based on an economic analysis and on other considerations such as storing, feeding and handling characteristics. Disinfectant dosages mentioned previously must be increased if hypochlorites are used. Calcium hypochlorite generally has 70 per cent available chlorine; sodium hypochlorite usually has 5 to 15 per cent available chlorine. It is usually preferred to use a solution feeder for calcium hypochlorite. Sodium hypochlorite must be fed through a solution feeder, as it is only available in liquid form.

An alternative to purchase of sodium hypochlorite is on-site generation. An economic analysis should be used to evaluate this method or any method of supplying a disinfecting chemical.

Use of ozone for disinfection may be desirable in regard to meeting haloform limits currently being considered by the USEPA. A cost comparison should be made between the use of ozone and removal of haloform precursor compounds.

7. Stabilization

Water leaving the treatment plant and entering the distribution system should be stable. Thus, it should neither be scale-forming nor aggressive for the temperatures experienced in the distribution system. Two ways of stabilizing water are (1) adjustments to pH and (2) addition of polyphosphates or silicates.

a. **Adjustments to pH.** Water is considered to be stable when it is at the point of calcium carbonate saturation equilibrium. At this point, calcium carbonate is neither dissolved nor deposited. If the pH is raised from this equilibrium level, water becomes scale-forming, depositing calcium carbonate. The water becomes aggressive if the pH is lowered.

An index developed by W. F. Langelier called the Langelier Saturation Index makes it possible to predict the tendency of a given water to deposit or dissolve calcium carbonate. The Langelier Saturation Index is equal to the actual pH of the water minus the pH at saturation. A positive value for the index signifies the water is oversaturated and has the potential to precipitate calcium carbonate. A negative number indicates the water is potentially aggressive. It is desirable to maintain the water at, or slightly above, the Langelier saturation equilibrium point in order to maintain a thin coating of calcium carbonate on the pipe interior. This coating protects the metal against corrosion.

Stabilization of water is most often associated with an upward adjustment of pH to control corrosion. However, there must be sufficient calcium ions present in solution for calcium carbonate to form. In low hardness waters, where there is a calcium ion deficiency, lime (CaO) should be added for raising the pH. It is economical and will serve as a calcium supply as well as bringing the pH up. In hard waters, there will be sufficient calcium ions present in solution. Thus, sodium hydroxide or soda ash should be added to raise the pH without adding to the hardness.

b. **Polyphosphate.** The addition of polyphosphate can be an effective method for scale and corrosion control. Maximum temperatures in the distribution system, retention time, and scaling potential are some of the factors which have an effect on the performance of the specific polyphosphate and on the dosage requirement. Generally, a low dosage of polyphosphate, less than 5 mg/l, can effectively prevent scale even in a severe scaling condition.

When adding polyphosphate for corrosion control, somewhat higher dosages may be required because it is necessary to form a protective corrosion inhibiting film throughout the distribution system. Phosphates react with iron and other minerals in water forming a positive-charged particle. This particle migrates to the cathodic area of a corrosion cell and deposits as a thin film which reduces the corrosion of the metal. After the protective film is established, dosages can be lowered while maintaining the film. Bimetallic (zinc) polyphosphate or zinc orthophosphate is usually more effective for corrosion control than sodium polyphosphate.

c. **Silicates.** Other additives which are sometimes used as a treatment for corrosion control include silicates. Sodium silicate in one of the various proportions of Na_2O and SiO_2 has been successfully used. It is a particularly popular treatment for waters with very low hardness, alkalinity, and pH less than 8.4.

8. Ion Exchange

Ion exchange is the reversible interchange of ions between a solid ion exchange medium and a solution. In water treatment applications, ion exchange is most often used for water softening, but can also be applied to demineralization by use of cation and anion resins.

a. **Softening by Ion Exchange.** The ion exchange process which removes hardness cations from a water supply is termed softening. Hardness is caused principally by the cations calcium and magnesium; however, cations such as barium, aluminum, strontium, and others also contribute to the total hardness of a water supply.

Ion exchange materials for softening purposes will most generally have exchange sites in the sodium form. Hydrogen form resins are also available, but they are not normally used for softening of drinking water supplies. Sodium cycle cation resins exchange sodium ions for the hardness cations, thus producing water with an increased sodium content and a greatly reduced total hardness. Sodium cycle resins will not appreciably change the total dissolved solids content.

Polystyrene resins are the most popular ion exchange softening materials in current use. Other substances which have been used as ion exchange media for softening purposes include natural greensand, processed greensand, synthetic silicates, sulfonated coal, and phenolic resins. The term "zeolite" has been applied to any material used as an ion exchange softening medium, but strictly speaking, it includes only greensands or synthetic silicates.

Softener equipment resembles vertical pressure filtration vessels and contains internal piping to accomplish backwash, regenerant distribution and effluent collection; a resin support such as graded gravel or quartz and the granulated resin are located in the lower half of the vessel. The vessel should be lined to minimize corrosion.

Capacities of 23 to 64 kg per m^3 (10 to 28 kilograins per ft^3) are generally achieved dependent on regenerant dosage and temperature. Values of 193 m^3/m^3/day (1 gpm/ft^3) minimum flow and 965 m^3/m^3/day (5 gpm/ft^3) maximum flow are generally used in determining size of the vessel. Resin bed depth will vary from 0.8 m to 1.8 m (30 inches to 72 inches) to maximize resin contact time and minimize pressure loss through the exchanger. Continuous operation, multiple exchanger vessels, and raw water blending can help accomplish consistent water quality as well as desired flow rates.

Water supplies, especially surface supplies, often contain materials which are detrimental to softener operation. Suspended solids must be generally limited to less than 0.06 mg/l suspended solids per mg/l hardness (1.0 mg/l per gpg) with a maximum acceptable limit of 10 mg/l total suspended solids. Hydrogen sulfide and free residual chlorine can be tolerated to 0.5 mg/l and 1 mg/l respectively; however, lower residual values are more desirable since both substances cause resin damage and consequently loss of exchange capacity.

The process for regenerating sodium cycle ion exchange resins generally involves three steps: (1) backwashing (2) application of a sodium chloride solution and (3) rinsing. Since downflow operation is most commonly used in small ion exchange water softeners, backwashing is required to loosen the media bed and remove any turbidity particles filtered out of the water during softening. Backwashing is performed at rates of 240 to 600 m^3/m^2/day (4 to 10 gpm/ft^2), depending on the temperature of the backwash water and the density of the medium. Backwash periods usually range from two to five minutes.

After the unit has been backwashed, a sodium chloride solution is applied to the medium in order to regenerate its softening capabilities. With a sufficiently high salt concentration, the calcium and magnesium ions in the medium are replaced by sodium ions. Sodium cycle resins are regenerated with brine solutions providing 96 to 224 kg of sodium chloride per m^3 (6 to 14 lb per ft^3) of resin; regeneration brines are usually 10 to 15 per cent solutions of salt. The strength of the brine solution and the contact time of the brine with the softening medium have a direct effect on the exchange capacity of the regenerated medium. Exchange capacity increases with increasing contact time. Contact times of 20 to 35 minutes are common. Installations in coastal areas may use seawater for regeneration, if the seawater is first disinfected and treated for removal of suspended matter. Sea water contains only about 3 per cent salt and the exchange capacity of a softener regenerated with sea water will be less than when regenerated with a 10 to 15 per cent salt solution.

Control of regeneration can be automatic, semiautomatic, or manual. Potable water systems should include automatic regeneration control based on a measured quantity of water passing through the exchange material with provisions for manual override and multiple regeneration based on actual water quality.

After regeneration, the excess brine solution must be rinsed from the unit before softening is resumed. About 2.7 to 12 m^3 (700 to 3200 gal) of rinse water is required for each cubic meter (35.3 ft^3) of softening material. The total time needed for backwashing, brining, and rinsing usually varies from about 35 to 70 minutes.

Disposal of the waste brine solution from the regeneration cycle is a problem which requires some attention. Disposal may be accomplished by evaporation ponds or by discharging into a sanitary sewer system.

b. Demineralization by Ion Exchange. Demineralization is the ion exchange process which removes the dissolved solids content of a water supply. Dissolved solids will contain both cations and anions and thus necessitate the use of two types of ion exchange resins. Demineralization processes have been devised to handle water with total dissolved solids (TDS) in a range from 500 mg/l to 2000 mg/l. A method for continuous demineralization utilizing a moving resin bed is currently being manufactured. Both fixed and moving bed ion exchange systems are applicable within the same TDS range.

Cation exchange resins for demineralization purposes have exchange sites in the hydrogen form and are divided into strong acid and weak acid classes. The anion resins commonly used are divided into strong and weak base classes.

Ion exchange demineralizers can be operated to produce an effluent with a TDS ranging from less than 10 mg/l to 200 mg/l. As the proposed MCL for TDS is 500 mg/l, demineralization costs can be reduced by operation at lower efficiencies or by blending raw water with treated water having a low TDS.

Dissolved organics, strong ozidizing agents, and suspended solids are harmful to ion exchange demineralizers. Organics, which may be irreversibly absorbed in the resin, and chlorine can be removed by carbon adsorption. Strong oxidizing agents can alter the exchange resin. Suspended solids can inhibit passage of water through the demineralizer and prevent intimate contact between the water and exchange resin. Suspended solids can be removed by filtration. High levels of iron and manganese may resist removal during regeneration.

Capacities for cation resins of 23 to 46 kg per m^3 (10 to 20 kilograins per ft^3) of resin are generally achieved dependent on regenerant type and dosage.

Cation resins are usually regenerated with sulfuric acid; however, hydrochloric acid may also be used. Hydrogen cycle resins are regenerated with sulfuric acid solutions providing 48 to 160 kg of concentrated (66° Baumé) sulfuric acid per m^3 (3 to 10 lb per ft^3) of resin. Hydrochloric acid solutions are used which provide 32 to 144 kg of 100 per cent hydrochloric acid per m^3 (2 to 9 lb per ft^3) of resin in the form of a 10 per cent solution. Anion resins usually are regenerated with sodium hydroxide (caustic soda) solutions providing 64 to 160 kg of caustic per m^3 (4 to 10 lb per ft^3) of resin applied as a 3 to 5 per cent solution.

Control of regeneration can be automatic or semi-automatic, or manual. The demineralizer equipment will be similar in appearance to softener equipment; however, there will be two vessels per unit. The internal piping will be basically the same. Flow loadings will be similar and waters containing high turbidity, hydrogen sulfide, and chlorine concentrations will be detrimental to demineralizer resins in the same manner as softener resins.

Disposal of demineralizer waste solutions from the regeneration cycle can be accomplished by first mixing the waste from the cation (acidic) and anion (basic) units in a neutralization basin and then adjusting the pH to comply with discharge regulations. When properly neutralized, demineralizer wastes may be discharged to a sanitary sewer system, if permitted by local conditions.

c. **Applicability and Recommendations**. The ion exchange process should be considered for any small treatment softening application. It is an excellent process for softening hard water, producing an effluent with a nominal hardness of zero under normal operating conditions. However, for municipal uses, it is neither desirable nor economical to soften an entire water supply to zero hardness. The softening costs can be reduced considerably by blending the zero hardness water with unsoftened bypass water. Thus a finished water with any desired degree of hardness can be obtained. Use of ion exchange softening is not recommended for persons on sodium-restricted diets.

The use of ion exchange systems for demineralization should be considered for treatment of water with less than 2000 mg/l TDS concentrations. Ion exchange demineralizers are capable of producing relatively pure water, hence blending of treated and untreated water is often desirable because of lower operation costs.

In addition to hardness and TDS reduction, the ion exchange process should be considered for removal of the following: arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, color, copper, iron, manganese, sulfate and zinc.

Some general advantages of ion exchange include low capital investment and mechanical simplicity. The major disadvantages are high regenerant chemical requirements and disposal of chemical wastes from the regeneration process. These factors make ion exchange more suitable for small systems than for large ones.

Disposal of the waste brine solution from the regeneration cycle is a problem which requires some attention. For small systems, disposal may be accomplished by evaporation ponds or by discharge into a sanitary sewer system. Regulatory agency requirements in a particular locality may be a controlling factor in selecting a disposal method.

9. Membrane Processes

Brackish waters are widely distributed over the United States and are found underground as well as in estuaries, rivers, and lakes. In some areas, brackish water may be the only available water for public supply and consequently must be treated. Two membrane processes are commonly used in desalting applications: electrodialysis and reverse osmosis. Electrodialysis (ED) uses electric current to transfer salts from feedwater through a membrane to a reject stream while reverse osmosis (RO) utilizes hydraulic pressure to force feedwater through a membrane to a product stream. Both processes use energy at a rate somewhat dependent upon the amount of salts to be removed.

a. **Electrodialysis.** Electrodialysis is the demineralization of water by the removal of ions through special membranes under the influence of a direct-current electric field. Until the early 1970's all commercial electrodialysis installations were of the fixed polarity type having an anode and a cathode at opposite ends. A polarity reversal system has since been developed in which each electrode intermittently changes electrode polarity to prevent membrane scaling. Newer membrane stack designs may contain more than one electrode pair to permit internal staging.

Operation of an ED system involves the application of a direct-current potential to the electrodes. Since the minerals in water dissociate into cations and anions, the positively-charged electrode, called the anode, attracts anions present in the water, and the negatively-charged electrode, called the cathode, attracts the cations.

Two types of special membranes are utilized in electrodialysis. The first can be permeated by cations but not anions. The second can be permeated by anions but not cations. These membranes are arranged in a stack, with cation-permeable membranes alternating with anion-permeable membranes. Feedwater enters the spaces between the membranes and the direct-current electric field is applied to the stack, causing the ions to migrate toward the electrodes. This results in a concentration of ions in alternate spaces between membranes, and the water in the other spaces becomes depleted in ions, or demineralized. Water is then drawn off from between the membranes in two separate streams, one containing most of the ions and the other relatively free of ions.

Electrodialysis units are generaly limited to a maximum of roughly 50 per cent TDS removal per stack to avoid excessive ion concentrations near the membranes. This situation, known as concentration polarization, can result in membrane scaling and degradation. Higher TDS removals are obtained by operating stacks in series. Product water recoveries usually range from 75 to 95 per cent per stack. Most plants employ 2, 3, or 4 stacks in series (although a single stack or more than four may be used) and are designed for 60 to 90 per cent water recovery and 60 to 95 per cent TDS removal. TDS removals over 90 per cent are seldom achieved in practice because power consumption and the danger of scaling increase with brine concentration.

One manufacturer of electrodialysis units recommends that flow through an ED installation not be allowed to drop below about two-thirds of the nominal design flow to prevent uneven internal flow and concentration polarization. This problem can be avoided by intermittent operation, system storage to equalize flows, or recycling.

Substances such as suspended solids, dissolved organics, hydrogen sulfide, iron, manganese, and strong oxidizing agents (chlorine, ozone, and permanganate) are deleterious to electrodialysis membranes. In order to remove these undesirable constituents, the feedwater for an electrodialysis facility should be pretreated as recommended by the ED supplier. The efficiency of the membranes may also be greatly reduced by scaling deposits. Hardness, barium, strontium, iron, manganese, and pH are important factors contributing to membrane scaling.

Scale prevention for fixed polarity ED units usually consists of the following:

- Acidification of the brine recirculation stream to prevent carbonate and hydroxide scaling.
- Limitation of calcium sulfate concentrations in the brine effluent.
- Reduction of iron to 0.3 mg/l and manganese to 0.1 mg/l through pretreatment.
- Diversion of a small flow for flushing of electrode compartments to remove gaseous hydrogen and prevent acidic build-up at the cathode and remove gaseous chlorine and prevent alkaline build-up at the anode.

Polarity reversal systems rely upon continuous reversal of compartment roles to prevent scale formation. Polarity is reversed at roughly 15 minute intervals so that inadequate time is provided for scale to build up between membranes, eliminating the need for acid or polyphosphate feed. However, regular in-place chemical cleaning is essential. Physical disassembly and cleaning may also be required periodically. Iron and manganese reduction is required with polarity reversal systems and product water recoveries are lowered by about 10 per cent by additional flushing requirements. In a large polarity reversal plant, electrode flushing streams could conceivably be returned to the feed flow. Membrane life of over five years is possible with proper care and favorable operating conditions.

The economics of electrodialysis is dependent on a number of factors, primarily the size of the facility, the characteristics of the feedwater, and the cost of power.

Process power requirements are roughly 0.8 to 2.6 kWh per m^3 (3 to 10 kWh per 1000 gal) of product water per 1000 mg/l reduction of total dissolved solids concentration. Additional pumping power requirements are usually 0.8 to 2.6 kWh per m^3 (3 to 10 kWh per 1000 gal) of product. Power inputs are dependent upon plant scale, the fraction of design flow being treated, and pump and equipment selection.

b. **Reverse Osmosis.** When two solutions containing different concentrations of minerals are separated by a semipermeable membrane, relatively pure water will migrate through the membrane from the more dilute solution to the more concentrated solution. This phenomenon, called osmosis, continues until the build-up of pressure on the more concentrated solution is sufficient to stop the flow. If there were no increase of hydrostatic pressure on the more concentrated solution, the process would continue until both solutions had equal concentrations of minerals. The greater the difference in concentration of solutions separated by a semipermeable membrane, the greater the rate of flow of water through the membrane. The amount of pressure which must be applied to the more concentrated solution in order to stop this flow is known as the osmotic pressure. If a pressure in excess of the osmotic pressure is applied to the more heavily mineralized water, relatively pure water will flow through the membrane in the opposite direction in a process called "reverse osmosis."

More process variations are available in RO than ED. Four RO configurations have been developed: hollow fine fiber, spiral wound, tubular, and plate and frame. The tubular and plate and frame configurations are comparatively very bulky and have not found wide acceptance due to space requirements and high initial cost. The hollow fine fiber and spiral wound configurations are more commonly used.

RO plant layouts generally feature flow schematics to maintain brine flow rates above a minimum. For example, a plant may have three stages, each having fewer modules than the previous stage. Above minimum flows are necessary to avoid localized build-ups of ion concentrations near membrane surfaces (concentration polarization) as in ED. The deleterious effects of this phenomenon in RO are higher osmotic pressure requirements, lower salt rejection, and increased likelihood of scaling and membrane hydrolysis. To aid in this respect, manufacturers recommend that feed stream flows not be lower than three-quarters of the nominal design flow. Uniformity of the feedwater flow may be maintained in the same manner as previously suggested for electrodialysis.

RO modules have been developed for application to a wide feedwater TDS range. As TDS contents increase, however, the hydraulic pressure required to maintain a constant product flow also rises while salt rejection efficiency declines. Pressures are held constant in normal operation, but power requirements increase with TDS for a given output because larger feedwater quantities must be pumped. Standard RO units (suitable for waters up to about 12,000 mg/l TDS) which are operated at 28 to 35 kg/cm^2 (400 to 500 psi) achieve 45 to 90 per cent product water recovery and 70 to 99 per cent salt rejection. Rejections of up to 95 per cent are typically achieved. Sea water desalting modules operate at about 56 kg/cm^2 (800 psi), achieve roughly 20 to 40 per cent recovery, and can exceed 99 per cent salt rejection. Power requirements for the standard modules generally vary from 0.3 to 3 kWh per m^3 (1 to 11 kWh per 1000 gal) of product water. Power requirements for sea water desalting are estimated to be 11 to 27 kWh per m^3 (40 to 100 kWh per 1000 gal) of product. RO power needs are virtually entirely attributable to pumping, but are dependent on a number of factors including plant scale, pump selection, and membrane age.

The essential element in the reverse osmosis method of demineralization is the semipermeable membrane. Several types and configurations of membranes are currently available, with the most widely used being various forms of cellulose acetate, diacetate, and triacetate, or polyamide membranes. The characteristics of these membranes vary and constitute an important design consideration.

RO membranes are subject to flux (water production) decline. This is a normal process primarily attributable to the high pressures of operation causing membrane compaction and aggravated by scaling, contamination, bacterial attack, and high temperatures. For plants operating around 28 kg/cm^2 (400 psi), flux declines of 10 to 20 per cent are typically encountered in the first 2000 hours of operation after which time little further decline occurs. Even higher declines are experienced in high pressure (sea water) systems. Flux reduction must be accounted for in initial system design. Polyamide membranes are thought to be more resistant to flux decline than are cellulose membranes of which the triacetate and diacetate forms are more resistant than the acetate form. RO membrane life expectancy is approximately 3 years with proper care and favorable operating conditions. Salt rejection does not necessarily decline with flux and can be maintained with careful operation.

Application of standard RO modules should be considered for waters up to about 12,000 mg/l TDS. Sea water RO units should be considered as an alternative to distillation at higher salt contents.

Due to lower water viscosities at higher temperatures, production by RO units increases with temperature. If the temperature becomes too high, however, compaction and irreversible flux reduction may result. The effects of temperature and pressure are closely related. At higher temperatures, hydraulic pressures must be lowered to prevent damage to the membranes. Cellulose membranes generally have a maximum normal operating temperature of 29°C (85°F). Polyamide membranes may be routinely subjected to temperatures as high as 35°C (95°F). Although both membrane types can withstand even higher temperatures for short periods without ill effects, optimal operating temperatures are generally lower than the maximum values recommended.

The performance of an RO installation as in the case of ED, is highly dependent upon a number of water quality parameters. Suspended solids and dissolved organics are both harmful to reverse osmosis membranes and should be removed by pretreatment as recommended by RO supplier.

The effect of oxidants upon reverse osmosis units varies. The cellulose membranes which are very susceptible to bacterial attack are somewhat tolerant of chlorine. A maximum continuous level of 1 mg/l free chlorine (or the equivalent oxidizing strength) is recommended. The threat to cellulose membranes from bacteria is sufficient in nature so that even well waters should be disinfected. Polyamide membranes are reputed to not be susceptible to biological attack, but are very sensitive to chlorine. Recommended maximum continuous exposures are 0.1 mg/l free chlorine at pH less than 8, and 0.25 mg/l at pH 8 or higher. While the polyamide membranes are apparently not subject to biological attack, they may be fouled by biological growths. Because they are believed to be selectively sensitive to chlorination rather than oxidation, the use of an alternative disinfectant may be feasible. However, no information on the effect of ozone on polyamide fibers is available. One manufacturer of polyamide membranes recommends the use of formaldehyde on an intermittent basis to control slimes.

Discussed earlier with respect to ED, the scale-related parameters, hardness, barium, strontium, iron, manganese, and pH are equally important to RO operations. Scale prevention measures commonly used include the following:

- pH adjustment to between 5.0 to 6.5 to prevent hydroxide and carbonate scaling.
- Iron and manganese reduction by pretreatment to levels recommended by RO equipment manufacturers.
- Use of a polyphosphate to inhibit calcium sulfate scaling.
- Limitation of calcium sulfate concentration in brine effluent.

c. **Applicability and Recommendations.** When confronted with treating brackish or highly mineralized waters, i.e., waters with high total dissolved solids concentrations, membrane processes should be considered.

Both electrodialysis and reverse osmosis are effective for reducing TDS concentration and both are suitable for small applications. Appropriate pretreatment is a major factor in successful operation of both processes.

Electrodialysis and reverse osmosis should also be considered for removing arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, chloride, copper, iron, manganese, sulfate and zinc. In addition, reverse osmosis is recommended for reduction of bacteria, radionuclides and color.

Advantages of ED as compared to RO include low pressure operation with no need for high pressure pumps, usefulness over a higher temperature range, longer membrane life, and a constant rate of production with time.

The primary disadvantage is a proportional increase in power consumption with increasing salt content which prevents ED from being economically competitive with RO at TDS levels of roughly 5000 mg/l and above. Also, because ED removes only charged particles, nonionics such as bacteria and dissolved gases remain in the product water. RO systems on the other hand, force product water through the membrane, thus removing dissolved gases, bacteria, viruses, and other nonionics as well as ionic species. Standard RO systems are effective for treating raw waters with TDS concentrations up to about 12,000 mg/l. Disadvantages of RO include flux reduction with time, shorter membrane life, and possibly significantly greater pretreatment chemical requirements.

Each situation should be individually examined to determine which process should be used for reduction of TDS levels. The economics of the situation will be the predominant factor in selecting ED or RO.

10. Fluoridation/Defluoridation

Fluoridation is the process of adding fluorides to drinking water in order to reduce tooth decay. Where necesary, fluorides are removed from water to prevent dental fluorosis.

a. Fluoridation. Fluorine is the thirteenth most prevalent element in the earth's crust and is present as fluoride in all natural waters to some extent. The concentration of fluoride in natural waters is generally less than what public health authorities consider to be optimal. Consequently, health departments often recommend adjustment of the fluoride level by the addition of small amounts of fluoride compounds to the water.

1. Health Effects of Fluorides in Water. In the 1920's and 1930's, the incidence of mottling of teeth (dental fluorosis) was definitively linked to the ingestion of waters that contained high concentrations of fluoride, generally in excess of 2 mg/l. It was also observed that persons suffering from dental fluorosis had very few dental caries, and further studies indicated that concentrations of fluoride near 1.0 mg/l greatly reduced the occurrence of dental caries in children without producing mottling of the teeth.

Inasmuch as fluoridation effects a marked decrease in the number of dental caries suffered by children, but high concentrations of fluoride cause dental fluorosis, the objective of fluoride adjustment in water treatment is to add enough fluoride to water to reduce dental caries while not adding enough to cause dental fluorosis.

Maximum concentrations which can be tolerated without the occurrence of dental fluorosis are given in Appendix A of this report. These maximum concentrations are dependent on the average daily intake of water by children in any particular location. The average daily intake of water is related to the average annual maximum daily air temperature, hence maximum fluoride concentrations are related to this temperature parameter. Higher temperatures dictate a lower maximum allowable level of fluoride.

2. Other Effects of Fluoride in Water. The small amount of fluoride ion added to drinking water does not cause taste or odor nor does it increase the corrosive properties of the water or cause encrustation in the distribution system or household plumbing. The use of hydrofluosilicic acid will reduce the pH and may contribute to corrosion.

3. Forms of Fluoride Used in Water Treatment. The most common compounds used in water fluoridation are sodium fluoride, fluosilicic acid, and sodium silicofluoride. The choice of which form is best for a water treatment plant is dependent largely on the cost of the compound, the availability, and the mode of fluoride application selected. Other compounds that have been used successfully by some water utilities include ammonium silicofluoride and fluorspar. However, these compounds are not recommended for routine application. The use of ammonium silicofluoride results in an increase in the ammonia content of the water, which may be objectionable because of the adverse effect of ammonia on chlorine disinfection, or may be desirable if chloramines are wanted. Fluorspar is not recommended for routine use because it is difficult to dissolve. Hydrofluoric acid presents such extreme safety and corrosion hazards that it is not considered suitable for general use as a water fluoridating agent.

4. *Application of Fluorides.* The number and variety of different fluoride application devices make it impossible to describe all of them in this report. In general, the chemical feeders used can be divided into two categories: dry feeders and solution feeders. Dry feeders can be further divided into gravimetric dry feeders and volumetric dry feeders. The choice between gravimetric or volumetric dry feeders must be made on the basis of feed rates, accuracy requirements, and overall cost.

Solution feeders consist of any of several types of positive-displacement pumps if pressure feed is used, or a paddle-wheel or bucket apparatus if gravity feed is used. Solution feeders are required for application of fluosilicic acid and may be used for feeding solutions of sodium fluoride, etc. Use of zeolite softened water is recommended for preparing strong solutions of sodium fluoride; softening reduces scaling problems. The type of feeder to be used should be selected on the basis of capacity, accuracy, durability, and corrosion resistance.

5. *Points of Application of Fluorides.* The most important factor in deciding on a point to inject fluoride is that all of the water must pass this point. If no such common point exists, more than one application point should be used. If fluoride is added to only a portion of the water and subsequently blended, the blending must include positive mixing of all water to insure uniform fluoride concentration. Fluoride is commonly injected into the water in the filter effluent conduit. If ground water is used as a source of water supply, the fluoride should be injected beyond the well head to insure adequate mixing and uniform dosage of fluoride and to prevent precipitation of fluoride compounds in the well. Multiple well installations often require a feeder at each well. It is generally more desirable to apply fluoride to the water in a water line leading to a storage tank, rather than away from a storage tank, because the flow toward the tank usually does not vary as widely or as rapidly as the flow away from the tank. The adjustment of the fluoride feed rate is much easier if the flow does not change rapidly.

The application of fluoride in a conventional water treatment plant should be after filtration, if possible. When fluoride is applied during the alum coagulation process, some fluoride will be lost. Lime softening will also remove some fluoride, especially if the concentration of magnesium in the raw water is high. If calcium hypochlorite and fluoride are both to be used, they should be applied as far apart as possible. If injected in close proximity, they would form a precipitate of calcium fluoride.

6. *Automatic Control of Fluoridation.* In many cases it is desirable to have the rate of feed of fluoride controlled automatically by a meter measuring the rate of flow of water to be treated. This is acceptable if the flowmeter to be installed is proven reliable and if the apparatus for feeding fluoride can operate at various speeds. If automatic control is used, provisions should always be made for manual control in the event of failure of the automatic control.

Medical evidence indicates that skin contact with excessive amounts of fluoride can cause extreme discomfort. Every effort should be expended to insure that personnel handling fluoride wear protective clothing and that adequate safety precautions be taken.

b. Defluoridation. Although fluoride in moderate amounts is beneficial in the prevention of dental caries, excessive concentrations of fluoride cause permanent mottling of tooth enamel and, in severe instances, pitting of the enamel and loss of teeth. The Interim Primary Drinking Water Regulations developed by the Environmental Protection Agency for maximum allowable concentration of fluorides are listed in Appendix A of this report. Fluoride MCL's are approximately two times recommended optimum fluoride levels.

Fluoride can be removed from water by percolating the water through granular beds of activated alumina, bone meal, bone char or tri-calcium phosphate. The fluoride is removed by a combination of ion exchange and adsorption. When activated alumina beds become saturated with fluoride, they are regenerated by treatment with a caustic soda solution. Excess caustic soda is removed by rinsing and neutralization with an acid. Mixed-bed demineralizers can also be used to reduce the fluoride concentration. A mixed-bed demineralizer will remove other minerals along with the fluoride. Additional methods of fluoride removal include sorption on precipitates of aluminum or magnesium hydroxide. Precipitation of substantial concentrations of aluminum or magnesium is required to effect major reduction in fluoride concentrations.

Saline water conversion methods, such as electrodialysis and reverse osmosis, have shown promise for achieving reduction of fluoride concentrations. These methods have been applied to brackish waters and have demonstrated their ability to remove fluoride, etc., along with other minerals.

Additional information in regard to defluoridation is included in section III A of this report, under Inorganic Chemicals.

c. **Applicability and Recommendations.** Adjusting fluoride concentrations in water supplies to optimum levels should be considered as a method for reducing tooth decay. Recommended water fluoridation compounds are sodium fluoride, fluosilicic acid and sodium silicofluoride. Fluoride should be applied after filtration in a conventional water treatment facility. Recommended defluoridation processes for small water treatment systems include reverse osmosis, electrodialysis, activated alumina, bone char, and, if used for removal of magnesium, excess lime softening.

Disposal of wastes from defluoridation treatment should be given careful consideration due to the toxic nature of waste.

B. WATER QUALITY CONTROL

Control of a water treatment facility involves more than valve turning and button pushing to start and stop equipment. In order to determine which valves to turn and which equipment to use the operator must be able to determine how well the plant is functioning. Not only does the operator need to know whether the MCL's are being met but also needs to know whether the treatment processes are under control. To determine all of this the operator will need laboratory analyses of the water and information provided by plant instrumentation.

1. Sampling and Analysis

Treated water must be sampled, for contaminants included in the drinking water regulations, at the proper locations and at the required frequency.

Analyses must be in accordance with the methods prescribed in the regulations. Since the inorganics, organic pesticides and radionuclides require extensive equipment and analytical skill these tests must be conducted by a certified laboratory. Approximate costs per sample for these analyses done by a commercial laboratory are as follows:

Inorganics	\$ 90 – \$150
Organics	\$160 – \$270
Radioactivity	\$ 60 – \$120

Most state health department laboratories can also perform these analyses.

The rest of the required analyses including turbidity (surface water or combination ground and surface water), chlorine residual (as a State allowed substitute for a portion of the coliform analyses), and coliform analyses would cost from \$4 to \$10 per sample in a commercial laboratory. To achieve proper results, the chlorine residual should be run almost immediately and the coliform analyses should be run within 24 hours. Use of a commercial laboratory for chlorine residual analyses is not feasible. Turbidity analyses are required daily for surface water plants and the cost in a commercial lab would be very high. The plant operator in all plants should be able to run the turbidity and chlorine residuals in a plant laboratory facility. Probably only those facilities of about 3800 m^3/day (1 mgd) and larger will want to run in-plant coliform analyses. For smaller plants either the county or state health department could probably run the coliform analyses.

In addition to the required tests, each plant should run the following tests in-plant as a control on the treatment processes:

Temperature
pH
Alkalinity

Temperature of the water is important because it influences the rate of chemical reactions, chlorine effectiveness, and the settleability of floc. The higher the water temperature the faster the chemical reactions and the better the settleability. The pH and alkalinity of a water are general control parameters since a number of the chemicals added to the water raise or lower the values of these parameters. Effects of pH and alkalinity have been discussed previously for contaminant removal and treatment techniques.

Other control tests may be required depending on the contaminant removed or the treatment processes used. For instance, where aeration is used in a lime softening plant, carbon dioxide could be a control parameter.

2. Laboratory Facilities

Each water treatment facility should have minimum laboratory facilities to do the following tests:

Turbidity
Chlorine Residual
pH
Alkalinity
Temperature

The laboratory size required for these tests should be about 11 m^2 (120 ft^2) including space for laboratory record keeping. A laboratory counter about 2.4 m (8 feet) long should be provided with storage space for equipment.

The cost* for a minimum laboratory facility would be about $7000. This can be broken down as follows:

Building	$2200
Furniture	$2300
Equipment	$1850
Supplies	$ 650
TOTAL	$7000

Additional facilities and equipment to do coliform tests would cost about $5500.

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* Cost based on engineering estimate.

3. Metering, Instrumentation, and Control

Metering at a small water treatment plant can be kept fairly simple. Generally all that is needed is a meter on the raw water and one on the finished water leaving the plant. The raw water meter can be a propeller type meter with flow indication only. The finished water meter should be a venturi flow tube or propeller meter which at least totalizes flow and possibly records flow.

Filter instrumentation and control for those supplies which are filtered should be provided with the filter package. The simplest form of control is a flow splitter ahead of the filters with a water level sensor on each filter which operates the filter rate controller. Another simple method of control is to operate the filters with a variable declining rate. However some state regulatory agencies may not approve this method. No indication of the filter backwash rate is required, if the flow has been physically limited to not exceed the maximum desirable rate. However, indication of headloss through the filter should be provided.

For surface water plants where a finished water turbidity sample is required daily, it may be advantageous to put a continuous turbidimeter on the filter effluent. This turbidimeter will have to be calibrated and may have some maintenance requirements principally related to keeping the optical system clean and aligned. A back up laboratory turbidimeter will still be required for raw water turbidity and for filtered water turbidity when the continuous unit is out of service.

A control panel should be provided in each water treatment facility. The panel should be part of the plant motor control center. The control panel should contain all indicators, totalizers, and recorders for the instrumentation discussed above in addition to remote indication of the status of all motor operated equipment. Actual on-off controls for the motors at the treatment facilities should be local to reduce instrumentation and control and to require the operator to go to the piece of equipment and observe it when starting or stopping it. Remote on-off controls can be employed for wells, distribution system pumping and other facilities located away from the water treatment plant.

C. WATER TREATMENT PLANT WASTE DISPOSAL

Disposal of wastes generated during the various water treatment processes must receive careful consideration. Selection of a disposal method will influence water treatment plant location and design.

1. Sources, Quantities, and Characteristics of Wastes

The wastes generated in a water treatment plant are composed of the natural solids removed from the raw water as well as the chemical precipitates resulting from chemical addition. The nature and quantity of the raw water solids will vary from one plant to another. For example, natural solids removed in a surface water plant are dependent upon sediment washed into the water supply by rainfall, seasonal algal growths, spring turnover in lakes, and other factors. The nature and quantity of chemical solids are a function of the chemicals added and the resulting precipitates.

a. Sources. Predominant water treatment plant wastes are waste solids in the sedimentation basin blowdown and the filter backwash water. Other wastes include spent brines from regeneration of ion exhange units and spent granular activated carbon.

b. Quantities of Wastes Produced. Quantities of wastes can best be determined not by measuring the waste stream, but through the use of chemical mass balance and other available data, such as suspended solids information.

1. Solids Produced by Turbidity Removal. Natural solids are normally removed in sedimentation basins with the chemically produced solids. If the suspended solids concentration (mg/l) in the raw water is available, then the amount of waste solids can be calculated directly. If suspended solids data are not available then an attempt should be made to correlate turbidity and suspended solids. The solids removed can be calculated as follows, assuming all natural solids are removed in the treatment process:

Solids produced (kg/day) = (suspended solids-mg/l) x (0.001) x (flow-m^3/day)

Solids produced (lbs/day) = (suspended solids-mg/l) x (8.33) x (flow-mgd)

2. *Solids Produced by Chemical Addition.* The amount of waste solids provided by chemical addition depends on the type of chemical added and the dose. The following paragraphs describe the chemicals utilized in each process of water treatment and the amount of solids produced.

Coagulation. A reasonable basis for estimating the chemical solids produced, when the coagulant alum is used, is indicated by the following reactions:

$$Al_2(SO_4)_3 \cdot 14\ H_2O \rightarrow 2Al^{3+} + SO_4^{2-} + 14H_2O \text{ (ionization)}$$

$$2Al^{3+} + 6OH^- \rightarrow \underline{2Al\ (OH)_3}$$

precipitate

Commercial alum contains about 17 per cent Al_2O_3 or 9 per cent Al^{+++}. Inerts are negligible. Essentially all aluminum added to the water is removed. The sulfate (SO_4^{--}) component of the alum remains in the water and appears as a residual mineral in the finished water.

Aluminum hydroxide [$Al(OH)_3$] resulting from alum addition can be computed from alum use in lbs or kg/day [Al_c] as follows:

$$Al(OH)_3 = [0.26]\ [Al_c]\ \text{(lbs or kg/day)}$$

The results of similar calculations made for other coagulants used in water treatment are shown in Table 25.

Table 25

SOLIDS PRODUCED BASED ON COAGULANT DOSAGE

Coagulant lbs or kg/day	Solids Produced (dry) lbs or kg/day
[Alc] Alum	[0.26] [Alc]
[Fec] Ferric Sulfate	[0.46] [Fec]
[Foc] Ferrous Sulfate	[0.40] [Foc]
[Pc] Polymers	[1.0] [Pc]
[Na_2SiO_3] Activated Silica	[0.3] [Na_2SiO_3]

Taste and Odor Removal. The chemicals generally used to oxidize taste and odor producing compounds are chlorine and potassium permanganate. Activated carbon is also used for taste and odor removal but acts as an adsorbent. The amounts of waste solids produced by the removal of tastes and odors are developed in a similar manner as those solids produced by the addition of coagulants. Table 26 presents the chemicals and resulting solids produced in removing taste and odors.

Table 26
SOLIDS PRODUCED FROM TASTE AND ODOR REMOVAL

Chemicals **lbs or kg/day**	**Solids Produced (dry)** **lbs or kg/day**
[AC] Activated Carbon	[1.0] [AC]
[$KMnO_4$] Potassium Permanganate	[0.55] [$KMnO_4$]
[Cl] Chlorine	None

Lime-Soda Softening. The lime-soda and ion exchange processes are the softening processes most commonly used to remove hardness from water.

Mass balance equations can be used to calculate the amount of solids produced by lime-soda softening. However, the solids are generally 2.5 times the quicklime dosage or two times the hydrated lime dosage.

Ion Exchange. The regeneration of ion exchange softening units utilizing sodium zeolite as the resin will produce a brine waste. This waste constitutes from 3 to 10 per cent of the treated water volume and contains substantial quantities of the chlorides of calcium and magnesium with small amounts of various compounds of iron and manganese. The precise amount of dissolved solids is dependent upon the amount of hardness removed from the water, time between regeneration, strength of the regenerant solution, and other factors.

pH Adjustment. Lime, caustic soda, or soda ash is sometimes used for pH adjustment in connection with alum or iron-salt coagulation. The dosage is adjusted to offset the acidic characteristics of the coagulant. The products of the reaction are soluble and this treatment does not contribute to chemical solids production.

Stabilization. Stabilization of lime-softened water may be accomplished by recarbonation, split treatment, or by the use of polyphosphates. Polyphosphates contribute nothing to solids production and precipitation induced by recarbonation or split treatment is accounted for by calcium and magnesium mass balances. These stabilization processes are not sources of chemical solids.

Disinfection. Disinfection is usually accomplished by chlorine and/or a combination of ammonia and chlorine (chloramine process). All reaction products are soluble; hence, disinfection produces no chemical solids.

Fluoridation. Some plants practice fluoride adjustment of the water. Any fluoride addition becomes part of the dissolved solids and does not contribute to the wastes.

c. **Characteristics.** Water treatment plant waste products exhibit various characteristics, depending on their source. Knowledge of these characteristics is basic to the selection of necessary waste disposal methods.

1. Waste Solids from Coagulation with Aluminum Salts. The wastes produced by coagulation with aluminum salts normally have a solids concentration of 0.5 to 2 per cent when they are removed from a sedimentation basin. The sludge is usually bulky, and gelatinous in consistency. It is difficult to dewater and a solids concentration of only 8 to 10 per cent can be achieved when it is thickened in a lagoon. Dewatering by mechanical devices such as the centrifuge has obtained a 15 to 20 per cent solids concentration. This concentration can only be attained if the sludge is first pretreated with a polymer. Without pretreatment, a 5-6 per cent solids concentration is an upper limit. Vacuum filtration has not been successful in dewatering waste solids from water treatment plants.

2. Waste Solids Produced from Coagulation with Iron Salts. The solids produced from the coagulation of water by iron salts are similar to those produced by coagulation with aluminum salts. The consistency and difficulty in dewatering are similar but the iron flocs generally are not as fluffy and gelatinous as alum.

3. *Waste Solids from Softening by Chemical Precipitation.* The characteristics of solids from the precipitation of hardness by lime and soda varies with the composition of the raw water and the dosages of chemicals used for softening. Waste solids collected in the settling basins of lime and lime-soda softening plants have been reported to range from 2 to 33 per cent solids concentration. Softening waste solids have been dewatered in lagoons to a solids concentration of 50 per cent. Mechanical devices such as centrifuges can dewater lime softening waste solids from 40 to 65 per cent solids. The greater the ratio of magnesium hydroxide [$Mg(OH)_2$] to calcium carbonate ($CaCO_3$) the lower the per cent lime softening waste solids concentration.

4. *Filter Wash Water.* Filter backwash water consists of fine natural and chemically precipitated solids that are not removed in the sedimentation basin. The solids concentration is low, averaging 0.08 per cent solids (800 mg/l total suspended solids). Filter wash water is usually 2 per cent of the water produced. Filter wash water by itself cannot be dewatered by mechanical means. When lagooned, the solids are allowed to settle and the supernatant is decanted.

5. *Spent Brine Solutions.* As discussed previously, the characteristics and amount of waste brines vary widely. The characteristics of a composite sample of spent brine discharged from one large zeolite plant are given in Table 27.

Table 27

ANALYSIS OF SPENT BRINE SOLUTION

Constituent	mg/l
Sodium and Potassium	3,325
Calcium	1,720
Magnesium	600
Chloride	9,600
Sulfate	328
Dissolved Solids	15,654

2. Waste Disposal Practices

Various methods of waste disposal have been used by the water utility industry. No specific method of waste disposal is most suitable for all wastes, as the properties of different types of wastes vary considerably.

a. **Direct Disposal.** The predominant method of disposal of backwash water and waste solids from water treatment plants has been direct discharge to surface waters. This method is now being abandoned due to regulations for discharges to water courses set by the Environmental Protection Agency. However, the EPA is considering direct discharge to the larger rivers such as the Missouri, Ohio, and Mississippi Rivers. Other than direct discharge, small water treatment plants have few reasonable methods of disposal available.

b. **Vacuum Filtration.** Vacuum filtration equipment is extensively used for dewatering wastewater treatment plant sludges, but its application to water treatment plant waste solids is limited. This method utilizes a cylindrical drum covered with a porous fabric made of metal mesh, steel coils, wool, cotton, nylon, saran, or one of the new synthetic fiber cloths as filtering media.

Alum waste solids have proven difficult to dewater by vacuum filtration. The gelatinous nature of the waste solids produced by alum almost precludes the use of vacuum filtration without precoating the filter with diatomaceous earth. The cost of precoating is high and the remaining solids-precoat mixture remains gelatinous in nature and may not be suited for ultimate disposal. Vacuum filtration of lime waste solids has been more successful but the waste solids were thickened prior to being vacuum filtered. High costs for equipment, operation and maintenance, and disposal of dewatered waste solids make vacuum filtration impractical for most small communities.

c. **Centrifugation.** Centrifuges are becoming more popular for dewatering water treatment wastes since they are able to handle dilute or thickened waste solids. Alum and softening wastes can be concentrated in a centrifuge to the per cent concentrations previously discussed.

High capital, operation, and maintenance costs make centrifugation beyond the financial means of most small communities. There is also the consideration of the cost of the ultimate disposal of the dewatered waste solids.

d. Drying Beds. Sand beds for drying water treatment waste solids are basically identical to those employed in sewage treatment. An underdrained sand bed may include decantation, but basically water is removed by drainage and air drying. A sufficiently shallow waste solids depth to allow cracking of the solids down to the sand-solids interface will accelerate drying and yield drier cakes.

Both the drainage and decantate can be discharged to the sanitary sewer or discharged to a surface water if the discharge meets permit requirements. The dried solids can be removed from the drying beds with a front end loader but must be disposed of, either in a sanitary landfill or by direct land application. A comparison between lagoons and drying beds shows that drying beds are more dependent on weather for successful operation, have more difficulties in removing sludge, have greater land requirements, incur higher capital costs, and require more operation and maintenance.

e. Lagoons. The most common treatment method presently utilized at water treatment plants for handling water treatment plant wastes is lagooning. In areas where ample land is available, which is generally true near small water treatment plants, lagooning can be quite economical. It takes advantage of natural temperatures (for evaporation and freezing) to aid in the dewatering of waste solids. Lagooning is not so much a disposal method as one for dewatering, thickening, and temporary storage.

Water is removed by decantation or by evaporation, with some drainage. Evaporation may provide a hard crust, but the remaining depth can turn into a viscous liquid upon agitation. In cold climates, freezing aids in dewatering by separating attached water from the solids. After thawing, the solids are in the form of small granular particles that settle readily and additional water can be decanted.

Solids removal is accomplished by a dragline or clamshell. Dumping the waste solids on the banks can be used to air dry them further prior to later disposal.

When sufficient land is available, filled lagoons can be abandoned, eliminating an ultimate disposal problem. In communities where this is not possible, alternatives include sanitary landfill, land application, and reuse of products from water treatment plant wastes such as the use of calcium carbonate as a soil stabilizer. Where waste solids remain in place indefinitely and the land is not reclaimed, unsightly spoiled land areas result.

Serious consideration should be given to the disposal of the decantate and underdrainage. Discharge to a surface water is recommended if the discharge meets permit requirements. An alternative method is discharging to the sanitary sewer. In water scarce areas, recycling through the water treatment plant has proven to be economical. In small water treatment plants, however, recycling of the decantate or underdrainage is economically questionable and can present operating problems. Recycle of the wash water can be a viable alternative even though it may not be operationally desirable.

While operating costs of lagoons are low, factors such as climate intermittent or continuous input, solids concentration of the waste, the availability of one or more lagoons, and the method and place of ultimate disposal will have a bearing on the land area required. Generally, at least two lagoons are needed for waste solids and a third lagoon for backwash water.

Current lagoon design practice includes the following:

1. Location free from flooding.

2. When necessary, dikes, deflecting gutters, or other means of diverting surface water.

3. A minimum depth of 4 to 5 feet.

4. 3 to 5 years solids storage volume.

5. Multiple cells.

6. Adjustable decanting devices.

7. Width of lagoon narrow enough to allow removal of waste solids by dragline, clamshell, scraper, tugger hoist, or any other mechanical equipment that might be employed.

The minimum embankment top width should be 8 feet to permit access of maintenance vehicles. Lesser top widths can be used for very small installations. The maximum inner and outer embankment slopes should not be steeper than 3:1, horizontal to vertical, and the minimum inner embankment should not have a slope less than 4:1, horizontal to vertical. The embankments should be seeded. Perennial type, low growing, spreading grasses that withstand erosion and can be kept mowed are most satisfactory for seeding of embankments. In general, alfalfa and other long-rooted crops should not be used in seeding, since the roots of this type plant are apt to impair the water holding efficiency of the dikes. Additional protection for embankments (riprap) may be necessary where dikes are subject to wind action or severe flooding of an adjacent water course.

Problems can exist with insect breeding but can be controlled with insecticides. Lagoons should be fenced to prevent access by unauthorized persons.

f. Discharge to Sanitary Sewers. An increasingly popular method of disposal of water treatment plant wastes is discharge to the sewage treatment facility via sanitary sewers. This would be particularly true for a small community served by sewage lagoons. If the sewage lagoons are of sufficient size to handle the water treatment wastes, then construction of separate facilities could not be justified.

Evaluation of the following considerations before the discharge of water treatment plant wastes to a municipal wastewater treatment plant is recommended:

1. Possible damage to sewer system due to clogging.
2. Amenability of the waste to existing processes, principally in mechanical treatment plants.
3. Hydraulic capacity of sewers, pumping stations, and sewage treatment facilities.
4. The effect of waste on the final plant effluent.

5. A direct connection between the water treatment plant waste disposal line and the sanitary sewer must be prevented.

6. Waste solids should be discharged over a 24 hour period, not as a slug flow. If this is not possible, some other time period, compatible with operation of the wastewater treatment plant, should be used.

g. Spent Brine Solutions. For a small community, disposal of spent brine solutions to the sanitary sewer is the most feasible method of treatment. The spent brine solution should not be discharged as a slug, but discharged continuously over a 24 hour period. This will avoid any damage to the wastewater treatment facility. A small holding basin can be used to equalize the discharge of the spent brine solution.

h. Summary of Waste Disposal Practices. The current restrictions on the discharges to lakes and streams have made water treatment plant designers look at alternatives to direct disposal. Small communities with small water treatment facilities are at a disadvantage since the costs are too high for them to use mechanical devices to treat water treatment plant wastes. The alternatives left to a small community are disposal to a sanitary sewer, lagooning, and drying beds.

The small community should be made aware of the fact that if their water treatment plant discharges a waste to a receiving stream or lake, a discharge permit called "The National Pollutant Discharge Elimination System Permit" (NPDES) must be obtained. This permit sets restrictions on the concentration of parameters, such as suspended solids and pH, that will be discharged to a stream or lake. If the water treatment plant does not discharge to a waterway, the permit is not required. This situation would occur if the plant disposed all their wastes to the sanitary sewer or they treated waste solids and/or backwash water with lagoons or drying beds and returned the decantate or drainage to the water treatment plant or disposed of it to the sanitary sewer. Therefore, it is advantageous for the small community to investigate the possibility of using their wastewater treatment plant to treat their water treatment plant's waste.

In many cases, the wastewater treatment facility may not be able to effectively treat wastes due to the increased amount of solids or volume contributed by the water treatment plant. In this case, the solids must be treated at the water treatment plant and disposed elsewhere.

For small systems, the most generally used method of dewatering water treatment plant wastes, except for spent brine solutions, is lagooning. The drainage and decantate can be discharged to a surface water or to the sanitary sewer. The dewatered waste in the lagoons must ultimately be removed and placed in a sanitary landfill or applied to the land.

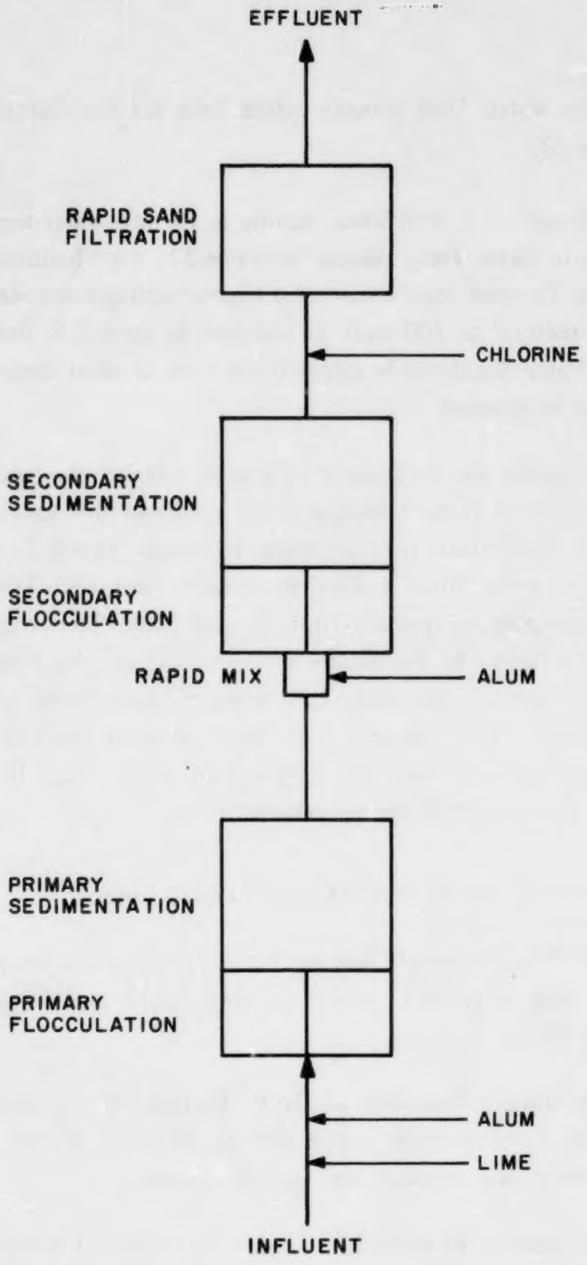
D. UNIT PROCESS COMBINATIONS

Generally, more than one unit process will be utilized in a treatment facility. A possible exception to this might be disinfection which could be the single unit process used for treatment of a well supply. Many process combinations could be used for water treatment. Combinations of unit processes which comprise conventional treatment facilities or package treatment plants are presented in the following sections.

1. Conventional Facilities

Four common types of treatment plants have been selected as examples of conventional unit process combinations constructed at the plant site. Design criteria and schematics for existing plants are presented to indicate how unit processes can be designed and combined into a treatment plant. The treatment plants that will be discussed include (a) turbidity removal, (b) ion exchange, (c) lime softening, and (d) iron and manganese removal.

a. Turbidity Removal. The turbidity removal plant at Garnett, Kansas removes about 100 mg/l suspended solids from the raw water taken from Lake Garnett and Cedar Creek. Rapid mix, flocculation, sedimentation, and filtration are combined to provide a two stage coagulation/filtration plant for the removal of turbidity. As shown on Figure 1, alum is used as the coagulant to remove turbidity and lime is fed to provide alkalinity for reaction with the alum and to control the pH. Chlorine is added prior to filtration for


EFFLUENT
RAPID SAND FILTRATION
CHLORINE
SECONDARY SEDIMENTATION
SECONDARY FLOCCULATION
RAPID MIX
ALUM
PRIMARY SEDIMENTATION
PRIMARY FLOCCULATION
ALUM
LIME
INFLUENT

GARNETT, KANSAS
WATER TREATMENT
PLANT SCHEMATIC

FIGURE I

disinfection of the water. Unit process design data for the Garnett plant is presented in Table 28.

b. Ion Exchange. A well water serving as the raw water supply for an AT&T installation in Grant Park, Illinois, contains 375 mg/l hardness as $CaCO_3$ and 2 mg/l of iron. To meet requirements for engine cooling water standards the hardness must be reduced to 100 mg/l. In addition, to meet U.S. Public Health Service Drinking Water Standards in effect at the time of plant design, the iron concentration must be reduced.

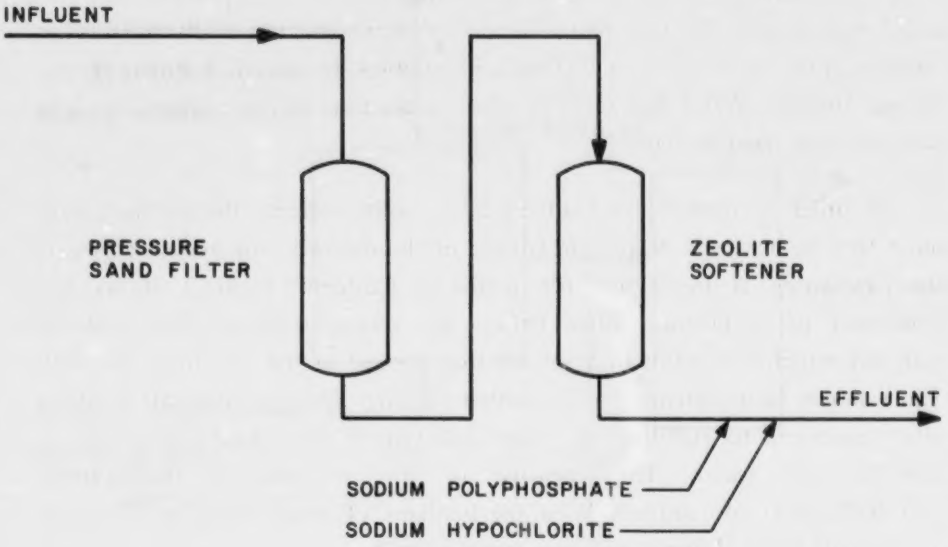
In order to remove the hardness by a zeolite softener the insoluble iron must first be removed to prevent fouling of the media in the zeolite softener, thus rendering it ineffective for removing hardness. Figure 2 shows the placement of a pressure filter before the zeolite softener. This removes turbidity which is a result of insoluble iron formed in the line from the well. The water is then softened by the zeolite softener. Sodium phosphate is added after treatment to stabilize the water and sodium hypochlorite is added to disinfect the water. The capacity of the softener is 16,200 grams (250,000 grains) of hardness. With the hardness of water equal to 375 mg/l, the liters of water softened between regeneration is

$$\frac{16{,}200}{0.375} = 43{,}200 \text{ liters or } 43.2 \text{ m}^3 \text{ (11,413 gallons)}$$

At a flow rate of 54.5 m^3/day (14,400 gpd), two regenerations are needed per day and the salt tank is refilled every three days. Additional design data are presented in Table 29.

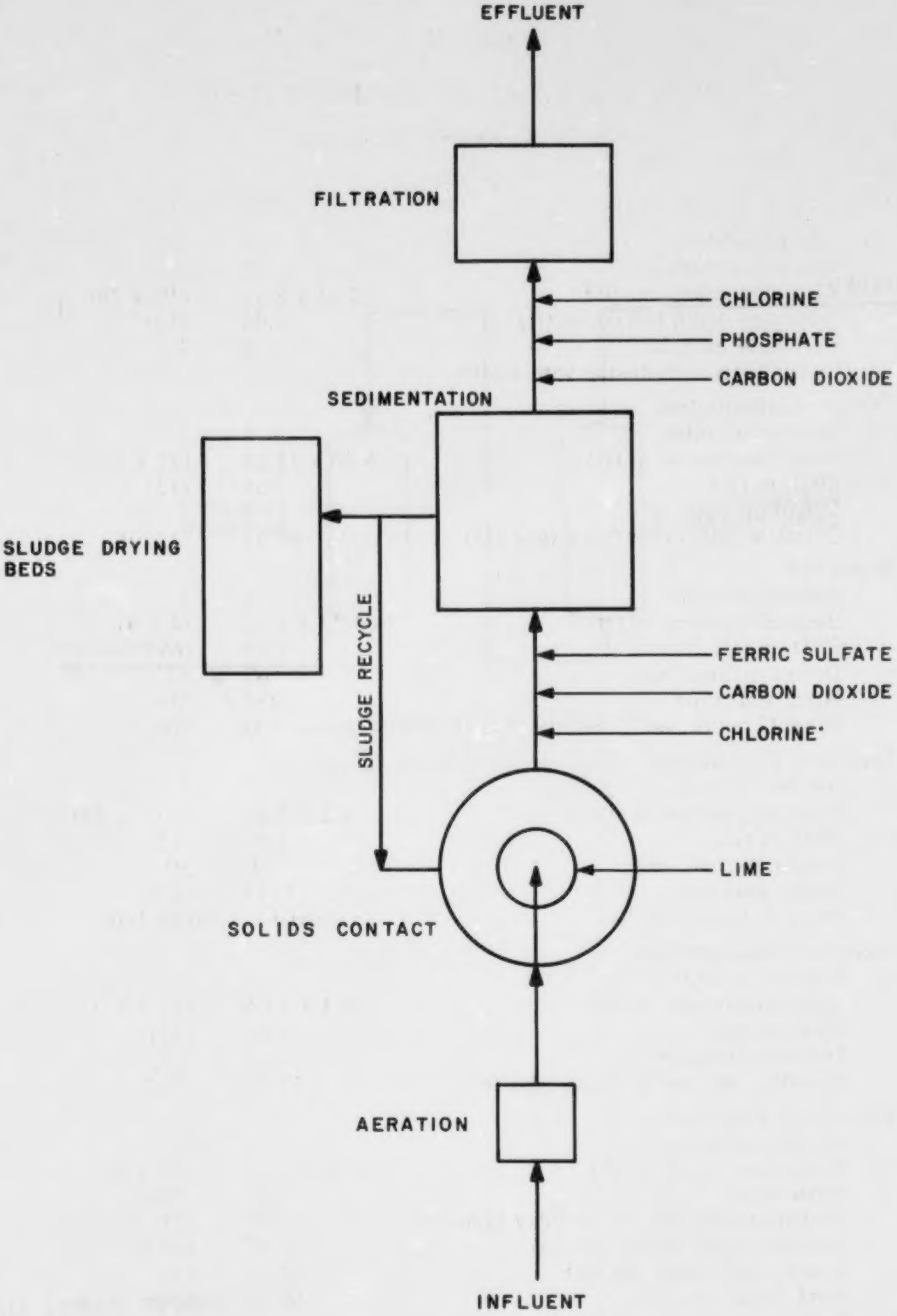
c. Lime Softening. The City of Troy, Kansas, has constructed wells along the Missouri River for raw water supply. The raw water is high in hardness and alkalinity, and contains iron and manganese.

The treatment process illustrated on Figure 3, consists of aeration, excess lime softening, two-stage recarbonation with intermediate settling, and filtration. The induced draft aeration serves a dual purpose, oxidizing iron and manganese so they can be removed, and removing carbon dioxide which will reduce the amount of lime needed for softening. Lime is then added in the solids contact unit, which mixes the lime into the water and allows settling of


INFLUENT
PRESSURE SAND FILTER
ZEOLITE SOFTENER
EFFLUENT
SODIUM POLYPHOSPHATE
SODIUM HYPOCHLORITE

GRANT PARK, ILL.
WATER TREATMENT
PLANT SCHEMATIC

FIGURE 2


EFFLUENT
FILTRATION
CHLORINE
PHOSPHATE
CARBON DIOXIDE
SEDIMENTATION
SLUDGE DRYING BEDS
SLUDGE RECYCLE
FERRIC SULFATE
CARBON DIOXIDE
CHLORINE
LIME
SOLIDS CONTACT
AERATION
INFLUENT

TROY, KANSAS
WATER TREATMENT
PLANT SCHEMATIC

IV-72-b

FIGURE 3

Table 28

GARNETT, KANSAS WATER TREATMENT PLANT

UNIT PROCESS DESIGN DATA

Design Flow, m^3/day (mgd)	3785	(1)
Primary Flocculation		
Number of units	2	2
Basin dimensions, m (ft)	3.05 x 8.53	(10 x 28)
Sidewater depth (SWD), m (ft)	3.66	(12)
Detention time, hr	1	1
Flocculators – hydraulic with baffles		
Primary Sedimentation		
Number of units	1	1
Basin dimensions, m (ft)	6.40 x 11.13	(21 x 36.5)
SWD, m (ft)	3.66	(12)
Detention time, hr	2	2
Overflow rate, m^3/m^2/day (gpd/ft^2)	45.57	(1120)
Rapid Mix		
Number of units	1	1
Basin dimensions, m (ft)	1.22 x 1.22	(4 x 4)
SWD, m (ft)	1.83	(6)
Detention time, sec.	62	62
Mixer, watt (hp)	2238	(3)
Mixer G factor, sec^{-1}	700	700
Secondary Flocculation		
Number of units	2	2
Basin dimensions, m (ft)	3.2 x 5.48	(10.5 x 18)
SWD, m (ft)	3.66	(12)
Detention time, min	30	30
Mixer, watt (hp)	1119	(1.5)
Mixer G factor, sec^{-1}	(variable – 20 to 100)	
Secondary Sedimentation		
Number of units	1	1
Basin dimensions, m (ft)	6.4 x 17.4	(21 x 57)
SWD, m (ft)	3.66	(12)
Detention time, hr	2.3	2.3
Overflow rate, m^3/m^2/day, (gpd/ft^2)	37.36	(918)
Rapid Sand Filtration		
Number of units	2	2
Filter dimensions, m (ft)	3.66 x 4.57	(12 x 15)
Filter depth, m (ft)	3.05	(10)
Design loading rate, m^3/m^2/day (gpm/ft^2)	120	(2)
Support gravel depth, cm (in)	26.67	(10.5)
Coarse sand depth, cm (in)	10.16	(4)
Sand depth, cm (in)	60.96	(24)
Surface wash units per filter	2	2
Backwash rate, m^3/m^2/min (gpm/ft^2)	0.76	(18.7)

Table 29

AT&T – GRANT PARK, ILLINOIS WATER TREATMENT SYSTEM UNIT PROCESS DESIGN DATA

Design Flow, m^3/day (gpd)	54.5	(14,400)
Pressure Filtration		
Number of units	1	1
Dimensions – inside diameter, cm (in)	76.2	(30)
Overall height, m (ft)	1.52	(5)
Design loading rate, m^3/m^2/day (gpm/ft^2)	120	(2)
Operating pressure, kg/cm^2 (psi)	5.27	(75)
Sand media depth, cm (in)	48.26	(19)
Backwash rate, m^3/min (gpm)	0.185	(49)
Softening		
Number of units	1	1
Overall dimensions, L,W,H, m (ft)	1.50 x 0.71 x 1.77	(4.92 x 2.33 x 5.83)
Capacity, grams (grains)	16,200	(250,000)
Maximum flow rate, m^3/min (gpm)	0.13	(34)
Backwash rate, m^3/min (gpm)	0.079	(21)
Area of bed, m^2 (ft^2)	0.4	(4.28)
Ion exchanger, m^3 (ft^3)	0.27	(9.5)
Salt tank refill, kg (lb)	272	(600)
Regenerations per refill	6	6
Salt per regeneration, kg (lb)	45	(100)

the resultant precipitates. The water is then recarbonated by the addition of carbon dioxide which lowers the pH. Recarbonation is accomplished using a swimming pool type injector chlorinator. Upon recarbonation additional precipitates are formed. Ferric sulfate added before the secondary flocculation-sedimentation unit will help remove these fine precipitates.

After the water is settled the pH receives final adjustment by carbon dioxide addition. The water is then filtered and pumped into the distribution system. Disinfection with chlorine can be accomplished at two different points. The design data for this plant are presented in Table 30.

d. **Iron and Manganese Removal.** A 1.5 mgd water treatment plant was designed to supplement an existing facility for the City of Cape Girardeau, Missouri. Raw water is taken from a well near the Mississippi River and treated in a water treatment plant that provides iron and manganese removal. The iron concentration is as high as 14 mg/l which exceeds the proposed secondary

Table 30

TROY, KANSAS WATER TREATMENT PLANT

UNIT PROCESS DESIGN DATA

Design Flow, m^3/day (mgd)	2271	(0.6)
Aeration		
Number of units	1	1
Type - induced draft		
Tower dimensions, m (ft)	1.22 x 1.22	(4 x 4)
Sidewater depth (SWD), m (ft)	4.26	(14)
Blower capacity, m^3/min (cfm)	28.04	(990)
Solids Contact		
Number of units	1	1
Basin dimensions, m (ft)	4.57 x 4.57	(15 x 15)
SWD, m (ft)	3.66	(12)
Upflow rate, m^3/m^2/min (gpm/ft^2)	0.055	(1.35)
Minimum detention time in floc zone, min	30	30
Dimensions flocculation zone,	3.55	(11.65)
top DIA, bottom DIA, m (ft)	1.27, 3.28	(4.16, 10.75)
Mixer, watt (hp)	560	(0.75)
Sedimentation		
Number of units	1	1
Retention at design flow, min	74	74
Overflow rate, m^3/m^2/min (gpm/ft^2)	0.045	(1.11)
Basin dimensions, m (ft)	4.57 x 4.57	(15 x 15)
SWD, m (ft)	3.35	(11)
Gravity Filtration		
Number of units	2	2
Filter dimensions, m (ft)	2.44 x 1.83	(8 x 6)
Filter depth, m (ft)	1.83	(6)
Design loading rate, m^3/m^2/min (gpm/ft^2)	0.105	(2.6)
Support gravel depth, cm (in)	25.40	(10)
Sand depth, cm (in)	68.58	(27)
Surface wash units per filter	2	2
Backwash rate, m^3/m^2/min (gpm/ft^2)	0.76	(18.7)
Sludge Drying Beds		
Number of cells	2	2
Surface area per cell, m^2 (acres)	526	(0.13)
Maximum sludge depth, m (ft)	0.46 - 0.61	(1.5 - 2.0)
Embankment slope, horz:vert	1:3	1:3

drinking water regulation for iron of 0.3 mg/l. Although the water is quite hard, softening is not practiced.

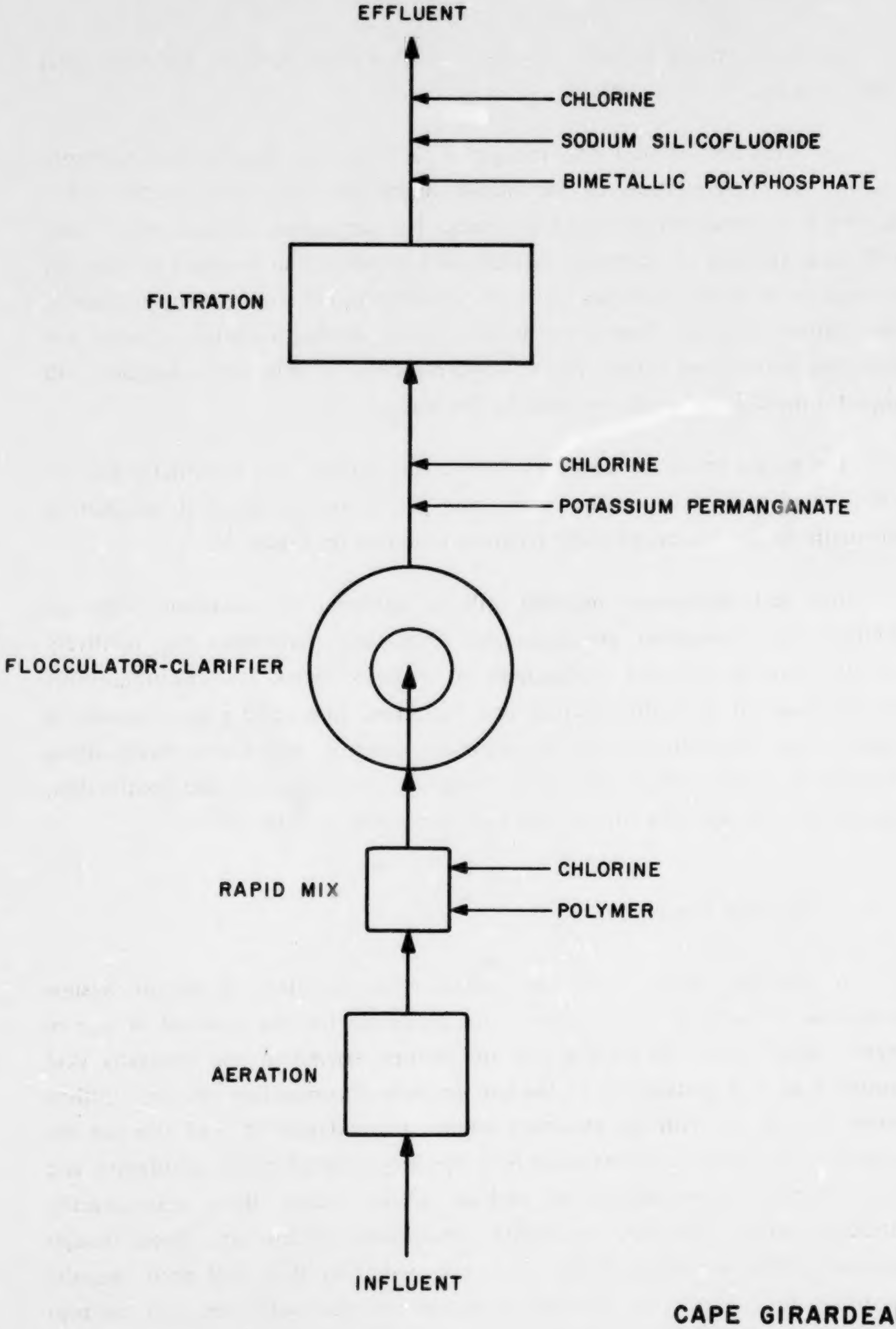
The presence of iron and manganese in water is objectionable primarily because the precipitation of the metals alters the appearance of the water, turning it a turbid yellow-brown to black. The deposition of these precipitates will cause staining of plumbing fixtures and laundry. The presence of iron and manganese in water supplies can also promote growth of microorganisms in distribution systems. These growths will reduce pipeline carrying capacity and may clog meters and valves. Higher concentrations of iron and manganese will impart a metallic or medicinal taste to the water.

The major treatment facilities include one aerator, one flocculator-clarifier basin, rapid mix, five pressure filters, and provisions for chemical addition. A schematic of the treatment plant facilities is shown on Figure 4.

Iron and manganese removal will be achieved by oxidation with air, chlorine, and potassium permanganate. Oxidation transforms the relatively soluble forms of iron and manganese to insoluble forms. The insoluble forms can be removed by sedimentation and filtration. Bimetallic polyphosphate is added after filtration to aid in corrosion control and water stabilization. Chlorine is added before and after filtration for oxidation and disinfection, respectively. Design data for the plant are presented in Table 31.

2. Package Plants

A package water treatment plant is a complete treatment system composed of two or more integral unit processes for the removal of one or more contaminants. Package plants are factory assembled and generally skid mounted so that installation at the site consists of connecting raw and finished water lines along with the electrical service. In moderate to cold climates the package plant should be enclosed in a building with adequate ventilation and heat. Factory construction of package plants makes them economically attractive when compared to plants constructed at the site. Even though package plants are designed for automatic operation they still need periodic attention to monitor the process, maintain chemical solutions, and perform required maintenance. Too often in the past package plants have been installed


EFFLUENT
CHLORINE
SODIUM SILICOFLUORIDE
BIMETALLIC POLYPHOSPHATE
FILTRATION
CHLORINE
POTASSIUM PERMANGANATE
FLOCCULATOR-CLARIFIER
RAPID MIX
CHLORINE
POLYMER
AERATION
INFLUENT

CAPE GIRARDEAU, MO.
WATER TREATMENT
PLANT SCHEMATIC

FIGURE 4

Table 31

CAPE GIRARDEAU, MO. WATER TREATMENT PLANT

UNIT PROCESS DESIGN DATA

Design Capacity, m^3/day (mgd)	5677	(1.5)
Aerators		
Number of units	1	1
Type–induced draft		
Dimensions, m (ft)	2.44 x 2.44	(8 x 8)
Sidewater depth (SWD), m (ft)	4.26	(14)
Loading rate, m^3/m^2/min (gpm/ft^2)	0.65	(16)
Fan motor, watt (hp)	560	(0.75)
Blower capacity, m^3/min (cfm)	110	(3900)
Flocculation–Sedimentation		
Number of units	1	1
Dimensions, dia., m (ft)	10.97	(36)
SWD, m (ft)	4.26	(14)
Overflow rate, m^3/m^2/day (gpm/ft^2)	0.04	(1)
Retention time - Sedimentation, min	94	94
Flocculator–Pulsator Type		
Pressure Filter		
Number of units	5	5
Dimensions, dia, m (ft)	3.05	(10)
SWD (minimum), m (ft)	1.52	(5)
Capacity, m^3/min (gpm)	0.89	(235)
Loading rate, m^3/m^2/min (gpm/ft^2)	0.12	(3)
Support gravel depth, cm (in)	25.4	(10)
Manganese greensand media depth, cm (in)	76.2	(30)
Anthracite media, effective size, mm	0.85-120	0.85-120
Anthracite media depth, cm (in)	20.32	(8)
Maximum backwash capacity, m^3/m^2/min (gpm/ft^2)	0.49	(12)

and expected to operate completely unattended resulting in unsatisfactory performance. Properly selected, operated, and maintained package plants can perform as well as plants constructed on site.

In addition to complete package plants, various unit processes are available ready for installation at the site. Ion exchange and membrane processes are examples of package unit process equipment. These unit processes have been discussed previously in section IV.

Four common uses of package plants, as discussed in the following paragraphs, include turbidity removal, taste and odor control, softening, and iron and manganese removal.

a. **Turbidity Removal.** Package plants designed for turbidity removal can treat water with a turbidity up to 200 JTU.

Each plant provides chemical feed systems, mixing, sedimentation, filtration, and disinfection. Package plants of this type, i.e., which provide clarification and filtration can also remove various inorganic contaminants. A comparison of the design features of package water supply treatment systems from three different manufacturers is presented in Table 32.

Table 32

COMPARISON OF PACKAGE WATER SUPPLY TREATMENT SYSTEMS

	Manufacturer		
Feature	A	B	C
Unit Processes	Mixing Flocculation Sedimentation Filtration Disinfection	Mixing Flocculation Sedimentation Filtration Disinfection	Mixing Flocculation Sedimentation Filtration Disinfection
Flow Range, m^3/day (mgd)	53-5700 (0.014-1.5)	26-1100 (0.007-0.28)	151-1100 (0.04-0.28)
Skid Mounted	Yes	Yes	Yes
Mixing-Type	Mechanical	Hydraulic	Mechanical
Sedimentation Type	Tube Settlers 2-1/2° or 60° Hexagonal	Tube Settlers 60° Chevron	Solids Contact
Filtration Type	Pump suction pulls water through filter	Gravity	Gravity
Media	Mixed	Standard bed or dual	Dual
Rate, m^3/m^2/day (gpm/ft^2)	300 (5)	120-210 (2-3.5)	210 (3.5)

b. Taste and Odor Control. Taste and odor causing substances can be effectively treated using package plants, which utilize either activated carbon for adsorption, potassium permanganate for oxidation, or a combination of these two chemicals. Powdered activated carbon can be fed either at the same point as the coagulation chemicals or directly to the filter. The point of application will depend upon the nature and concentration of substances to be adsorbed. Some substances are adsorbed quite rapidly, suggesting that the activated carbon should be applied directly to the filter. However, only small dosages of activated carbon should be used to prevent excessive head loss and potential passage of the carbon through the filter. Much of the carbon fed to the raw water is not effective in removing dissolved taste and odor because it is tied up with alum floc and turbidity. In certain instances, greater carbon contact time is required necessitating carbon application to the incoming raw water. Potassium permanganate could be fed along with the coagulation chemicals in the rapid mix unit to oxidize tastes and odors. Potassium permanganate would be added in place of activated carbon.

c. Softening. Package plants designed for turbidity removal can be used for partial softening. Lime is fed to the rapid mix unit and there are no provisions for recarbonation or a second stage lime addition. The limited waste solids handling capabilities restrict the amount of softening that can be accomplished. Partial softening presents the potential problem of calcification of the filter media and tubes. Certain maintenance steps must be taken to prevent calcification from becoming a serious problem. This use of the package plants would not be generally recommended.

d. Iron and Manganese Removal. Package treatment plants designed for turbidity removal can also be used for iron and manganese removal. Either potassium permanganate or a chlorine solution can be fed to the rapid mix to oxidize the iron and manganese. The precipitated iron and manganese are then coagulated and removed in a manner similar to the removal of turbidity with sedimentation and filtration.

To reduce chemical costs another type of package plant for iron and manganese removal is available. This plant uses aeration followed by filtration as the treatment system. Induced draft aeration is followed by gravity filtration while pressure aerators and filters are used together. This type of iron and

manganese removal system should not be used when the concentration of either contaminant is high. An iron concentration of several mg/l may cause the filter to plug up resulting in short filter runs. Concentrations of manganese of about one mg/l and above may not be fully oxidized by air alone; additional treatment would be required.

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V. UPGRADING EXISTING FACILITIES

If an existing water treatment plant cannot comply with the maximum contaminant levels for drinking water, upgrading the facility should be considered. Various methods of upgrading existing facilities are available. Upgrading techniques suitable for small water treatment facilities are discussed subsequently. Included are physical, chemical, and operation and maintenance modifications.

A. POLYMER ADDITION

When upgrading existing facilities is considered, the use of a polymer to aid the coagulation, sedimentation, or filtration processes should be evaluated. Polymer addition can improve water quality through increased process efficiency at relatively low capital cost.

As coagulant aids, polymers increase the size and thus the settling rate of floc. This is accomplished by adsorption, charge neutralization, and bridging between particles. For maximum efficiency, the type of polymer, dosage and point of addition must be determined for each application. Most polymers are expensive but only small dosages are required, generally in the range of 0.1 to 1.0 mg/l. Proper dosage and the right polymer, as determined by jar or pilot tests, is of importance because an excessive or insufficient dose, or the wrong polymer, can produce a poor floc.

Polymers, used as filtration aids, increase the strength of the floc and thereby lengthen filter runs and reduce the incidence of turbidity breakthrough. Required doses are small, generally less than 0.1 mg/l. Testing must be performed to determine the optimum dose of polymer for use as a filtration aid. The optimum dose exists when the terminal headloss is reached simultaneously with the first sign of increasing filter effluent turbidity. When used to improve filter efficiency, polymers should be added directly to the filter influent. Filtration aids should only be used in those filters having surface wash equipment or air/water backwash facilities to insure removal of the deeper penetrating floc during backwash. The polymer used as a filtration aid will not normally be the same type which may have been used as a coagulation or settling aid.

There are a number of commercial polymers currently available. Either naturally occurring or synthetic polymers can be used. Polymers are available in both dry and liquid forms. Since the dry polymers are not easily dissolved, special mixing and feeding equipment is required. Liquid polymers can be fed with metering pumps and then educted to the point of application. Polymers are also discussed in section IV A4, Clarification.

B. FILTER MEDIA REPLACEMENT

Existing rapid sand filters may be converted to dual or mixed media filters by replacement of the existing single media. Some structural modifications may be required to allow adequate media expansion during backwash.

The most common type of dual media filter consists of a coarse to fine arrangement of anthracite coal and sand. Primary benefits of dual media filters compared to conventional rapid sand filters are longer filter runs and improved finished water quality. Dual media filters are discussed in detail in section IV A5, Filtration.

Typical mixed media filters contain coal, sand and garnet in a coarse to fine configuration. Mixed media filters have several advantages over conventional rapid sand filters including higher capacity, capability to filter poorer quality influent, and longer filter runs. Use of mixed media filters will provide optimum filtration efficiency and will produce lower finished water turbidities than single or dual media filters. Additional information on mixed media filters is discussed in section IV A5, Filtration.

C. ACTIVATED CARBON REPLACEMENT OF FILTER MEDIA

Granular activated carbon can be used in conjunction with conventional filtration as a method for upgrading an existing treatment facility. A layer of activated carbon may be used to replace most of the sand in a conventional filter; most states require some minimum depth of sand under the carbon. Activated carbon may also be used to replace coal in dual media filters. When used as a filter media replacement, activated carbon functions as both a turbidity removal and adsorption unit. Finished water quality can potentially be enhanced without construction of additional filters or carbon columns. Detailed information on granular activated carbon is provided in section IV A3, Adsorption. For most taste and odor removal requirements a contact time of 5 to 7-1/2 minutes is acceptable. Haloform or haloform precursor removal requires a contact time of 12 to 15 minutes. Replacement of a portion of the filter media with granular activated carbon could reduce the plant capacity. Each potential application of media replacement by granular activated carbon should be evaluated by a knowledgeable engineer.

D. RAPID MIX ADDITION

Effective coagulation involves intimate mixing of the coagulant and the water. Existing water treatment plants with inefficient or overloaded rapid mix facilities or without any means for coagulant mixing, will not effectively remove turbidity or other contaminants from water. If chemical mixing by means of pumps is currently utilized, the chemicals may not be adequately mixed because of failure to achieve uniform distribution. Existing rapid mix chambers without mechanical mixing should also be evaluated. Baffling alone may not provide adequate coagulant mixing. Mechanical rapid mix provides a controlled, efficient unit process for the mixing of chemicals with the water being treated. Addition of or improvement to rapid mix facilities will aid the clarification process and thus improve finished water quality. Additional information on rapid mixing is contained in section IV A4, Clarification.

E. FLOCCULATION ADDITION

Flocculation is a principal mechanism in removing turbidity and various other contaminants from water. Inefficient or overloaded flocculation facilities should be upgraded. If an existing treatment plant has rapid mix and sedimentation facilities without flocculation, the addition of flocculation facilities could enhance finished water quality. Flocculators that use only baffles for mixing usually perform well at only one flow rate. Provision of variable mechanical mixing will enable the flocculation process to be effective for varying flow rates. The flocculation process is discussed in detail in section IV A4, Clarification.

F. CHEMICAL CHANGE OR ADDITION

Upgrading existing water treatment facilities may involve change of a chemical currently used or use of a new chemical. For example, if iron and manganese removal is desired, and only aeration is being used, addition of chemical oxidation will improve removal of manganese. Laboratory and plant scale tests may be used to select a coagulant better suited to the raw water quality. A coagulant aid or filter aid may also be used as discussed previously. Another method to be considered when upgrading water treatment facilities is chemical addition for pH adjustment to prevent corrosion in the system.

G. TUBE SETTLERS

An economic alternative to construction of additional sedimentation basins is installation of tube settlers in existing sedimentation basins. Use of tube settlers in this manner will produce an effluent of higher quality than is possible by using the existing basin only.

Two basic tube settling systems are currently utilized: (1) parallel 5 cm (two inch) square tubes inclined at 60° from the horizontal, and (2) parallel 2.54 cm (one inch) hexagonal tubes inclined at 5° from the horizontal. In the 60° inclined tubes, the sludge slides down the tubes and is collected beneath them. The 5° inclined tubes must be cleaned by backwashing with filtered water as the basin is drained.

When tube modules are installed, they should not be located near areas where turbulence could reduce their effectiveness. In horizontal flow basins, the inlet end should remain uncovered by the tubes to allow inlet velocity dissipation. In radial flow basins, the required modules can be placed in a ring around the basin periphery, leaving an open area to dissipate turbulence. The top of the tubes should be located 0.6 to 1.2 m (2 to 4 ft) below the water surface. In general, the 0.6 m (2 ft) minimum should be used in shallow basins. The 1.2 m (4 ft) submergence is used only in basins with a sidewater depth of 5 to 6 m (16 to 20 ft). These settling modules may utilize radial support beams in circular basins or support beams spanning the width in rectangular basins. In basins which have radial launders, it is often possible to suspend the modules from the launders.

In some cases there is a tendency for floc build-up to eventually bridge the tube openings and a blanket of solids on top of the tubes results. Methods of removing this accumulation include lowering the water level of the basin below the top of the tubes or occasional use of a water stream or compressed air to flush out the attached floc.

Recommended tube settler loading rates range from 120 to 240 m^3/m^2/day (2 to 4 gpm/ft^2). Selection of a specific overflow rate depends on existing clarifier configuration, water temperature, existing clarifier overflow rate, and desired effluent turbidity. More detailed information relative to the size, capacity, and configuration of these settlers, and their adaptability to existing sedimentation basins, may be obtained from manufacturers of such equipment. The use of tube settlers for a particular application should be evaluated by an engineer.

H. IMPROVED HYDRAULIC CONDITIONS

When upgrading water treatment facilities is necessary, hydraulic conditions of existing basins may be improved by use of baffles, by modifying inlet and outlet conditions, or by reducing pipe velocities below 0.6 m/sec (2 ft/sec).

Either horizontal or vertical baffles may be used to prevent short-circuiting in flocculation basins. Judicious baffling may be added as required or existing baffles rearranged to enhance flocculating conditions.

Properly designed inlets and outlets are also necessary to avoid short-circuiting through a basin. Inlets must be designed to distribute the water uniformly over the cross section of each basin. Adequate outlets must be provided to prevent excessive overflow rates and consequent breakup of floc or suspension of settled solids from floor of basin. Freely discharging weirs have a tendency to break fragile floc. Therefore, submerged weirs are recommended to provide an effective outlet arrangement. Inlet and outlet arrangements are discussed in more detail in section IV A4, Clarification.

When upgrading an existing facility is considered, plant piping should be reviewed in regard to its configuration and to the velocity of flow through it. Velocities in piping following flocculation should not exceed 0.6 m/sec (2 ft/sec) to reduce floc breakup because of turbulence. Excessive bends, drops, etc. also increase turbulence, and thus enhance floc breakup.

I. IMPROVED OPERATION AND MAINTENANCE

Regardless of how well a water treatment plant is designed, if it is not operated and maintained correctly, the treatment process or processes will not perform effectively. Therefore, upgrading various aspects of plant operation and maintenance is a prime consideration.

1. Operator Training and Qualifications

Even in the smallest plants with the simplest types of treatment, only qualified personnel should be in charge. Where experienced operators are not available locally to control the operation of a water treatment plant, a qualified operator should be employed from outside the community or a local person should receive adequate training to become a properly certified operator.

Training courses may be used as a means of upgrading an operator's qualifications. It is recommended that operators participate in training courses on a regular basis, as advancements in the knowledge and techniques of treatment processes are constantly being made. Locally available in almost every state, these courses are sponsored by the state departments of health, universities, and state and national technical associations.

In addition to training courses, numerous states utilize an operator certification program as a means of providing improved plant operation and to enhance the professional status of water plant operators. Currently, 39 states have a mandatory certification program, nine states have a voluntary program and two states have no certification program.

Another method of improving the operation of a water treatment plant involves employing an engineer or an operator from a larger facility as a consultant. Also, one operator might be employed by several small plants. The operator would rotate from plant to plant as required.

2. Improved Monitoring and Surveillance

The purpose of making analyses and tests is to control treatment, record performance, comply with regulations. and indicate means for improved performance. Control tests should be used to show that the water has been properly prepared for each major process, that each process is performing effectively, and that the finished water quality is adequate. Accurate metering of both water and chemicals is necessary because inaccurate feeding of chemicals could be economically wasteful and potentially hazardous to the health of the community.

As an aid in upgrading plant performance, the following control tests can be used:

Continuous Turbidity Monitoring
Chlorine Residual
pH
Alkalinity
Temperature

Use of the following equipment can be used to assist the operator in improving plant performance:

Raw water and plant effluent meters
Filter control
Raw water and plant effluent turbidimeters
Residual chlorine recorder

Control tests, metering, instrumentation, and control are discussed in more detail in section IV B, Water Quality Control.

In addition to water quality monitoring on the plant site, samples taken regularly from the distribution system should be examined to ensure that applicable drinking water regulations are met and to ensure that the water is of high quality when it reaches the consumer.

J. REGIONALIZATION

As discussed in section II D, Alternatives to Treatment, physical consolidation of facilities may be desirable for some small water treatment systems. However, regionalization of treatment or distribution facilities is neither feasible nor desirable for all small water systems. Other aspects of regionalization should be considered in an attempt to upgrade existing facilities. For example, management and administrative functions could be combined; county, parish or township public service districts could be formed to operate and maintain several facilities; and a central laboratory could be used by several small water systems.

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VI. COST DATA

Initial investment costs and operation and maintenance costs are presented herein for conventional water treatment facilities and for package water treatment plants. The cost curves are intended to assist in evaluating proposed new facilities and modifications to existing facilities.

Key to the development of these costs is the relationship of population to water consumption. Provided in Table 33 are the water use projections used in this report.

Table 33

TREATMENT PLANT DESIGN CAPACITY

Population (1)	Plant Per Capita Design Rate (2) m^3/c/day	(gpcd)	Design Plant Capacity (3)=(1)x(2) m^3/day	(gpd)
25	9.0	(2400)	227	(60,000)
250	4.6	(1200)	1136	(300,000)
1,000	1.9	(500)	1893	(500,000)
2,500	1.1	(300)	2839	(750,000)
5,000	0.8	(200)	3785	(1,000,000)
10,000	0.6	(150)	5678	(1,500,000)

The plant per capita design rates in Table 33 are based on water usage or usage rate and on an assumed amount of storage in the system. For the smallest svstem, no storage was assumed in the system; therefore, the plant design rate is based on the maximum rate of usage which would be for watering lawns or gardens. For the largest system, a normal maximum day per capita usage was assumed along with adequate storage in the system to supply any water requirements which would exceed this rate.

Cost data presented are appropriate for average situations. They should permit development of preliminary cost estimates for water treatment facilities when used with judgment regarding local conditions. An engineer should be engaged to review local conditions and to evaluate the manner in which this report's cost information will be used.

It is emphasized that the cost data contained in this report cannot be used as a substitute for detailed cost estimates based on a particular water treatment situation. Among the many variables which affect actual construction costs are the following:

(a) Characteristics and complexity of specific plant design.

(b) Current and projected labor costs.

(c) Contractors' attitudes regarding their need for work.

(d) Availability of materials.

(e) Climate and seasonal factors.

Local factors can also have a significant effect both on construction and on operation and maintenance costs.

It is essential that the user of the cost estimating methods presented in this report review all introductory material. In particular, the information discussed at the beginning of section VI A, Capital Costs, and section VI B, Operation and Maintenance Costs, should be understood prior to use of the cost curves and tables.

For the most part, each cost curve extends from 227 m^3/day (0.06 mgd) to 5680 m^3/day (1.5 mgd). Exceptions are the cost curves for diffused aeration, clarification processes, filtration, disinfection methods, and package plants. In general, diffused areation is not economical for treatment plants with design flows less than 1890 m^3/day (0.5 mgd).

For small water treatment systems, the most applicable range for clarification, filtration and disinfection unit processes overlaps with the most applicable range for package plants. This situation is reflected in the cost curves. The solid portion of each cost curve indicates the most applicable range for that unit process or package plant. The dashed portion of these cost curves indicates the plant design flow range in which conventional unit processes or package plants might be utilized.

A. CAPITAL COSTS

Cost curves were developed for treatment processes judged applicable to small water treatment systems. These curves relate capital costs to quantities of water treated and to population served. Estimates of complete water treatment plants or additions to existing plants may be developed on the basis of these relationships.

Yard piping, fencing (where applicable), and sitework have been included in the curve for each unit process. When adding unit process costs together some of these items may overlap; this may cause the total cost to exceed actual plant costs by 10 to 25 per cent.

Cost data, developed specifically for this report, are based on information from various manufacturers and on the experience and judgment of the investigators. Preliminary designs and engineering cost estimates were developed for each unit process at various low rates. Estimates of construction costs are representative of average price levels as of January, 1977. The Engineering News Record Building Cost Index of that date had a value of 1489.

Included in the capital costs are necessary construction costs, a contingency amount and engineering, legal and administration fees. A cost for fencing is provided for mechanical aeration, diffused aeration, rapid mix, flocculation, sedimentation, ozone contact chamber and waste disposal (lagoons). For each of the other treatment methods an enclosure is recommended and separate cost curves are provided.

Capital costs for unit proceses, package plants and enclosures are developed as follows:

(1) Construction cost – included are necessary costs for equipment, materials, installation, freight and start-up.

(2) Sitework – estimated as 10 per cent of the construction cost.

(3) Electrical – estimated as 20 per cent of the construction cost.

(4) Contingency – estimated as 10 per cent of the total of construction cost, sitework, electrical and fencing (if applicable).

(5) Engineering, legal and administrative – estimated as 15 per cent of the total of construction cost, sitework, electrical, fencing (if applicable), and contingency.

Equipment and materials capital costs are based on use of prefabricated, modular, or factory built/field assembled units to minimize on-site construction. Design parameters used for sizing unit processes should not be generally applied to all water treatment situations. Design parameters should be selected on the basis of raw water characteristics for each application.

Enclosure capital costs include costs for a prefabricated insulated metal building, foundation, and necessary plumbing and electrical facilities.

Separate cost curves for enclosures and treatment facilities have been provided to allow the enclosure cost to be deleted where climate would not be detrimental to treatment process efficiency or equipment integrity. It must be recognized, however, that the enclosure cost curve includes the foundation. Therefore, if an enclosure is judged not necessary for a specific situation, then a foundation cost must be added to the capital cost for the treatment process in question.

Capital costs for laboratory facilities are not provided in this section of the report, but are given in section IV B2, Laboratory Facilities. Estimates of construction costs do not include costs for high service pumping, treated water storage or extraordinary costs related to large amounts of rock excavation, site dewatering or piling.

1. Unit Processes

Figures 5 through 33 are the capital cost curves for various water treatment unit processes. Prior to use of the cost curves, the estimator should carefully review the following summaries of equipment, material, and design criteria used in developing the unit process capital costs. If local conditions require use of different design criteria or equipment, the capital costs must be revised accordingly.

An example calculation illustrating use of the unit process capital cost curves is provided in section VI C.

a. Mechanical Draft Aeration. Capital costs for this aeration process are based on an induced draft aeration unit located above a basin. The following design criteria are used to develop capital costs for mechanical draft aeration:

(1) ten trays vertically spaced approximately 0.305 m (12 in) apart.

(2) tray area furnished is 3.9 cm^2 per m^3/day (40 ft^2 per mgd).

(3) air supply rate of 0.019 m^3/min per m^3/day (2,500 cfm per mgd).

Capital costs for this unit process include costs for the following equipment and materials: prefabricated aluminum induced draft aeration tower, blower, motor, basin, foundation, necessary controls, associated valves and piping, and fencing. Refer to Figure 5 for the mechanical draft aeration capital cost curve.

b. Diffused Aeration. Diffused aeration capital costs are based on a system which consists of an aeration tank and the means of supplying compressed air to this tank. The following design criteria are used:

(1) basin depth of 3 m (10 ft).

(2) basin width from 3 to 6 m (10 to 20 ft).

(3) width to depth ratio less than 2:1.

(4) retention time of 20 minutes.

(5) air supply of 0.67 m^3 of air/m^3 of water (0.09 ft^3/gal).

The following equipment and materials are included in the diffused aeration capital cost curve: steel aeration tank, foundation, positive displacement air compressor and motor, air piping, air diffusers, inlet filter silencer, necessary controls, associated valves and piping, and fencing. Refer to Figure 6 for the diffused aeration capital cost curve.

c. **Activated Carbon Beds.** For the activated carbon adsorption process, capital costs are based on a fixed-bed gravity feed system which uses an 8x30 mesh size granular carbon. Also included is an empty tank for storage and dewatering of the spent activated carbon. To develop the activated carbon bed capital cost curve, the following design criteria are used:

(1) media depth of 1.2 m (4 ft).

(2) surface loading rate of 160 m^3/m^2/day (2.7 gpm/ft^2).

(3) contact time of 11.25 minutes.

(4) three cells, each handling one-third of the total flow.

The capital cost curve for activated carbon beds is based on costs for the following equipment and materials: prefabricated steel three-cell gravity filter shell including underdrain system and supporting gravel, activated carbon, surface wash system, backwash system, spent carbon storage tank, necessary valves, piping and manual controls. Refer to Figure 7 for the activated carbon bed capital cost curve, along with a capital cost curve for an enclosure.

d. **Activated Alumina Columns.** Capital costs developed for the activated alumina adsorption process are based on a duplicate-column, gravity-feed system using grade F-1, 28x48 mesh size alumina. Also, included in these capital costs are facilities for regenerating the alumina. Regeneration involves backwashing with raw water, sodium hydroxide and sulfuric acid. To prepare the activated alumina column capital cost curve, the following design criteria are used:

(1) media depth of 1.07 m (3.5 ft).

(2) surface loading rate of 180 m^3/m^2/day (3 gpm/ft^2).

(3) contact time of 8.7 minutes.

(4) two cells, each handling one-half of the total flow.

The following equipment and materials are included in the activated alumina capital cost curve: prefabricated steel shell, underdrain system, activated alumina, supporting gravel, surface wash system, backwash system, associated valves and piping, necessary manual controls, chemical feed system and storage tank for each of the regenerative chemicals, and a mechanical mixer for the sodium hydroxide storage tank. Refer to Figure 8 for the activated alumina capital cost curve, and the capital cost curve for an enclosure.

e. **Rapid Mix**. Capital costs for the rapid mix process are based on a mixing basin with a flash mixer and a by-pass pipeline with a static mixer. The static mixer is provided as backup for use when the mixing basin or flash mixer is out of service. The volume of the mixing basin is specified by the retention time; the velocity gradient determines the power needed by the mixer. To prepare the rapid mix capital cost curve, the following design criteria are used:

(1) one basin.

(2) retention time of 45 seconds.

(3) velocity gradient of $G = 750 \text{ sec}^{-1}$.

The following is a list of equipment and materials included in rapid mix capital costs: steel basin, foundation, flash mixer, metal stairs, metal grating, mixer support, by-pass pipeline with static mixer, necessary controls, associated piping and valves, and fencing. Chemical feed equipment is not included in the rapid mix cost estimates. Section VI A1 (o), Chemical Feed, contains various chemical feed system costs. Refer to Figure 9 for the rapid mix capital cost curve.

f. **Flocculation**. The flocculation process capital costs are based on utilizing vertical turbine flocculators in the flocculation basins. The retention time determines the volume of the basin. The power of the vertical turbine flocculator is calculated from the velocity gradient (G). The following design criteria are used:

(1) retention time of 30 minutes.

(2) velocity gradient of $G = 50 \text{ sec}^{-1}$.

(3) two basins, each handling one-half of the total flow.

(4) one vertical turbine flocculator per basin.

Capital costs for flocculation include costs for the following equipment and materials: steel basin, foundation, vertical turbine flocculator, influent and effluent devices, metal stairs, flocculator support, metal grating, necessary controls, associated valves and piping, and fencing. Refer to Figure 10 for the flocculation capital cost curve.

g. **Sedimentation**. Capital costs for the sedimentation process are based on a sedimentation basin sized to allow settling of coagulated particles and furnished with equipment for removal of the waste solids. The following design criteria are used to develop the capital cost curve for the sedimentation process:

(1) retention time of 4 hours.

(2) surface loading rate of 16 m^3/m^2/day (400 gpd/ft^2).

(3) two basins, each handling one-half of the total flow.

Sedimentation capital costs include costs for the following equipment and materials: steel basin, foundation, mechanical waste solids collection equipment and support, submerged orifice peripheral weir, metal grating, necessary controls, associated piping and valves, and fencing. Refer to Figure 11 for the sedimentation capital cost curve.

h. **Flocculator-Clarifier**. Flocculation and sedimentation can both be achieved in a flocculator-clarifier. Design criteria used to develop the flocculator-clarifier cost curve are as follows:

(1) flocculation zone retention time of 30 minutes.

(2) sedimentation zone surface loading rate of 16 m^3/m^2/day (400 gpd/ft^2).

(3) two basins, each handling one-half of the total flow.

The flocculator-clarifier capital cost curve includes the following equipment and materials: steel basin, foundation, mechanical waste solids collection equipment and support, vertical turbine flocculator, submerged orifice peripheral weir, metal stairs, metal grating, necessary controls, associated piping and valves, and fencing. Refer to Figure 12 for the flocculator-clarifier capital cost curve.

i. **Ion Exchange Softening**. Capital costs for the ion exchange softening process are based on a complete softening system. This system includes facilities for blending softened and raw water, and facilities for automatic backwash and regeneration. Design criteria used to develop the capital cost curve for ion exchange softening are as follows:

(1) softening 75 per cent of the plant flow and blending with the remaining raw water.

(2) automatic regeneration and backwash triggered by time-clock control.

Capital costs for ion exchange softening include costs for the following equipment and materials: complete ion exchange softening system with automatic controls, associated valves and piping, cation exchange resin, brine tank and necessary regeneration equipment. Refer to Figure 13 for the ion exchange softening capital cost curve and an enclosure capital cost curve.

j. **Pressure Filtration**. Pressure filtration capital cost curves are developed for three surface loading rates. Costs are based on multiple unit filters with automatic control of the backwash cycle. The following design criteria are used to develop capital costs for pressure filtration:

(1) surface loading rates of 120, 240 & 360 m^3/m^2/day (2, 4, & 6 gpm/ft^2).

(2) three to seven filter cells, each cell handling an equal portion of the plant flow.

The capital cost curves for pressure filtration are based on the following equipment and materials: multiple package pressure filters, associated valves and piping, automatic controls, surface wash system, backwash system, and media. Variance in media costs is not significant in the cost of the filter. Refer to Figure 14 for pressure filtration capital cost curves and enclosure capital cost curves.

k. **Gravity Filtration.** For the gravity filtration process, capital costs curves are developed for different surface loadings. Variance in media costs is not significant in the cost of the filter. Provisions are also included for automatic control of the backwash cycle. To prepare the capital cost curves for gravity filtration, the following design criteria are used:

(1) surface loading rates of 120, 240 & 360 m^3/m^2/day (2, 4, & 6 gpm/ft^2).

(2) three cells, each handling equal flows.

Capital cost curves for gravity filtration include costs for the following equipment and materials: package triplicate unit gravity filters, associated valves and piping, automatic controls, surface wash pump, backwash pump, and media. Refer to Figure 15 for gravity filtration capital cost curves and enclosure capital cost curves.

1. **Demineralization.** For the demineralization process, capital costs are based on a two-bed system. This system includes facilities for blending demineralized and raw water, and facilities for automatic regeneration. Regeneration involves backwashing with sulfuric acid and caustic soda.

The following design criteria were used to develop the demineralization capital cost curve:

(1) demineralizing 75 per cent of the plant flow and blending with the remaining raw water.

(2) two-bed system.

(3) automatic regeneration and backwash triggered by conductivity control.

(4) influent TDS of 1000 mg/l was assumed.

The capital cost curve for demineralization includes costs for the following equipment and materials: two-bed demineralization system, cation and anion exchange resins, necessary regeneration equipment, associated valves, piping and automatic controls. Refer to Figure 16 for the demineralization capital cost curve and a capital cost curve for an enclosure.

m. **Electrodialysis.** The electrodialysis capital cost curve was developed for a complete multiple-stage electrodialysis system. Costs were obtained for standard units as rated by the manufacturer for operation with a raw water TDS concentration of 1500 to 4000 mg/l. For these electrodialysis units, predicted per cent water recovery ranges from 65 to 85 and predicted per cent TDS removal ranges from 82 to 96. Local water quality may change the rated capacity of these units.

Electrodialysis capital costs include costs for the following equipment and materials: skid-mounted reverse polarity electrodialysis unit with membrane stacks, rectifiers, low pressure feed pump, brine recirculation pump, chemical cleaning equipment, cartridge filters, necessary valves, piping and automatic controls. Refer to Figure 17 for the electrodialysis capital cost curve. The enclosure capital cost curve for electrodialysis is shown on Figure 18.

n. **Reverse Osmosis.** The reverse osmosis capital cost curve was developed for a complete reverse osmosis treatment system. Costs obtained were for standard units as rated by the manufacturer for operation with a feed of 1500 mg/l $NaCl$ at 400 psi, 25°C (77°F), and 75 per cent conversion. Local water quality may change the rated capacity of these units.

Capital costs for reverse osmosis include costs for the following equipment and materials: skid-mounted, membrane-type reverse osmosis unit with hollow fine fiber membranes, high pressure pumps, cartridge filters, acid and polyphosphate feeding equipment, necessary valves, piping and automatic controls. Refer to Figure 19 for the reverse osmosis capital cost curve. Presented on Figure 20 is a capital cost curve for an enclosure for this unit process.

o. **Chemical Feed.** Capital costs have been determined for the following chemical feed systems:

(1) powdered activated carbon.

(2) coagulants.

(3) hydrated lime.

(4) polymer.

(5) polyphosphate.

(6) chlorine.

(7) ozone.

(8) calcium hypochlorite.

(9) sodium hypochlorite (purchased).

(10) sodium hypochlorite (on-site generation).

Chemical feed system capital costs include all equipment essential for the storage, mixing and application of the chemical. Duplication of equipment, i.e., a standby system, is not provided for powdered activated carbon, polyphosphate, ozone or sodium hypochlorite (on-site generation) chemical feed systems. The cost for a standby feeder or metering pump is included in the chlorine, calcium hypochlorite and sodium hypochlorite (purchased) chemical feed system capital costs. A standby chemical feed system is included in the coagulant, hydrated lime and polymer capital cost curves. For each chemical feed system, separate capital cost curves have been developed for selected chemical dosage concentrations. Figures 21 through 30 show capital cost curves for various chemical feed systems and their enclosures.

1. Powdered Activated Carbon. Powdered activated carbon dosages used to develop capital cost curves for this chemical feed system are 20 mg/l or less and 50 mg/l. Refer to Figure 21 for the powdered activated carbon capital cost curves and for enclosure capital cost curves.

2. Coagulants. The coagulant chemical feed capital cost curve is based on a system dosage capability of up to 50 mg/l. Refer to Figure 22 for the coagulant capital cost curve and for an enclosure capital cost curve.

3. Hydrated Lime. Hydrated lime capital cost curves are based on chemical feed systems capable of feeding 50 mg/l or less, 100 mg/l and 200 mg/l of hydrated lime. Refer to Figure 23 for these capital cost curves and for enclosure capital cost curves.

4. Polymer. Polymer dosages used to develop capital cost curves are 0.5, 1, 3 and 5 mg/l. Refer to Figure 24 for polymer chemical feed capital cost curves along with enclosure capital cost curves.

5. Polyphosphate. The polyphosphate chemical feed capital cost curves are based on a system dosage capability of up to 5 mg/l. Refer to Figure 25 for these capital cost curves and for enclosure capital cost curves.

6. Chlorine. The chlorine chemical feed capital cost curves are based on selected chlorine dosages of 5 mg/l and less and 10 mg/l. Shown on Figure 26 are chlorine capital cost curves and capital cost curves for enclosures.

7. Ozone. Capital costs for the ozone disinfection process are based on the on-site generation of ozone and its application within a basin sized to provide adequate contact time. Costs included are for air feed ozone generating equipment.

The following design criteria are used for the ozone capital cost curves:

(1) contact time of 15 minutes.

(2) ozone dosages of 1.5, 5 and 10 mg/l.

Capital costs for ozone disinfection include costs for the following equipment and materials: ozonator, steel basin, foundation, metal stairs, and fencing for the contact basin. Refer to Figure 27 for the ozone capital cost curves and also for enclosure capital cost curves. Enclosure capital costs are based on enclosures sized only for the ozone generating equipment.

8. Calcium Hypochlorite. The calcium hypochlorite chemical feed capital costs are based on calcium hypochlorite dosages of 1.5, 5 and 10 mg/l. Refer to Figure 28 for calcium hypochlorite feed system capital cost curves and enclosure capital cost curves.

9. Sodium Hypochlorite. Sodium hypochlorite capital cost curves are based on chemical feed systems capable of feeding 1.5, 5 and 10 mg/l sodium hypochlorite dosages. These cost curves are applicable when sodium hypochlorite is purchased. Refer to Figure 29 for these capital cost curves and for enclosure capital cost curves.

10. Sodium Hypochlorite (On-Site Generation). The capital costs developed for sodium hypochlorite on-site generation facilities are based on using salt in a brine solution as opposed to sea water. Sodium hypochlorite dosages of 1.5, 5 and 10 mg/l are used. Capital costs for this disinfection process include costs for the following equipment and materials: sodium hypochlorite generator, brine system, brine tank, and the recycle tank. Refer to Figure 30 for capital cost curves for sodium hypochlorite on-site generation facilities and for enclosure capital cost curves.

2. Laboratory Facilities

A capital cost curve for laboratory facilities is not presented in this report. A cost curve is not necessary as one laboratory size is applicable for the range of treatment facility sizes considered. Refer to section IV B2, Laboratory Facilities, for a laboratory capital cost.

3. Waste Disposal Facilities

Capital costs for a lagoon waste disposal facility are based on disposal of waste solids from a turbidity removal plant. The following design criteria are used:

(1) turbidity of 50 JTU.

(2) alum dosage of 30 mg/l.

(3) retention time of 2 years.

(4) influent waste solids consisting of 5 per cent solids.

(5) two-cell lagoon.

Capital costs include costs for excavation, inlet and outlet appurtenances, seeding and fencing. Refer to Figure 31 for the lagoon capital cost curve.

4. Package Plants

The capital cost curve for package water treatment plants is based on a complete treatment facility. Included are costs for the following equipment and materials: coagulant, polymer, and chlorine chemical feed systems; mechanical flash mixer; mechanical flocculator; sedimentation; filters; surface wash and backwash systems; steel basins; and necessary valves, piping and automatic controls. Refer to Figure 32 for the package plant capital cost curve and for an enclosure capital cost curve.

5. Upgrading Existing Facilities

Section V of this report discusses various methods available for upgrading water treatment facilities. Capital cost curves for some of these methods are provided in section VI A1, Unit Processes. Thus, it is not necessary to discuss them in this section. The rapid mix capital cost curve is shown on Figure 9 and the flocculation capital cost curve is shown on Figure 10. Refer to Figure 24 for the polymer (coagulant or filtration aid) capital cost curves. Cost information for use of a new chemical is shown on Figures 21 through 30.

Capital costs are not presented for replacement of filter media, chemical change or improvement of hydraulic conditions, operator training, or monitoring and control as these are best determined for each water treatment situation.

The only upgrading method to be discussed in detail here is use of tube settlers. Capital costs for this process are based on installation of settling tubes in an existing sedimentation basin. The following design criteria are used to develop capital cost curves for the tube settling system:

(1) settling tube surface loading rate of 180 m^3/m^2/day (3 gpm/ft^2).

(2) 5 cm (2 in) square tubes inclined at 60° from the horizontal.

(3) adequate tubes are provided to settle the existing plant flow.

Capital costs for this method of upgrading water treatment facilities include costs for PVC settling tubes and the support beams. Refer to Figure 33 for the settling tube capital cost curve.

B. OPERATION AND MAINTENANCE COSTS

Based on the average cost information presented, total annual operating and maintenance expenses for various plant components may be developed. Where it was not possible to base operation and maintenance cost data on manufacturers' information, cost elements were estimated.

Actual costs may vary appreciably from the estimated average costs in this report. However, when used with judgment, the data presented should be of value for preliminary cost estimates. The user should recognize the inherent limitations of such estimates and should develop applicable operating cost estimates based on local conditions.

Cost data were adjusted to indicated cost levels for January 1977. To update these costs, they may be trended to the applicable date by using the "Wholesale Prices and Price Indexes" as published by the Bureau of Labor Statistics, U.S. Department of Labor. The Wholesale Price Index for January 1977 is 188.4. If knowledge of a specific local situation indicates a more appropriate updating method, such information should be utilized.

Major elements of operation and maintenance costs considered include labor, power, supplies and chemicals. Annual labor cost curves are provided for the following types of treatment facilities:

Type 1 – minimal treatment such as disinfection only.

Type 2 – package plants.

Type 3 – conventional facility with chemical addition, clarification, filtration and disinfection.

Type 4 – conventional facility described above with one additional special process such as ion exchange, electrodialysis, reverse osmosis, activated alumina, etc.

The labor costs indicate the total requirements to adequately operate and maintain the facility. Man-hour requirements for these treatment facilities are based on desirable levels of operator attention for each type of plant. For the

Type 1 and Type 2 facilities it is estimated that one part-time operator is required. For the Type 3 and Type 4 facilities, round-the-clock operation with one to two operators per shift is recommended. The average hourly earnings rate (wages plus fringe benefits) used is $7.30. This rate is based on the National Average Earning Rate published by the U.S. Department of Labor, Bureau of Labor Statistics, for nonsupervisory employees in the public utility industry, under "Water, Steam and Sanitary Systems", SIC Code 494-7, as of January 1977. If local conditions indicate a different earnings rate, such information should be used. Refer to Figure 34 for annual labor cost curves for Type 1 and Type 2 facilities. Refer to Figure 35 for annual labor cost curves for Type 3 and Type 4 facilities.

Power cost curves are provided for the applicable unit processes and for package plants. These power costs are based on equipment power requirements, and estimate of the operating time of the equipment, a power cost of $0.03 per kWh and a 10 per cent contingency.

Cost curves for supplies include costs for normal annual upkeep and improvement materials. Unit process supply cost curves include costs for oil, grease, belts, chains, etc. Enclosure supply cost curves include cleaning materials, paint, etc. The supply costs are based on 5 per cent of the equipment cost for each unit process and package plant, 2 per cent of the construction cost for each enclosure and a 10 per cent contingency. Supplies cost curves for electrodialysis and reverse osmosis are exceptions. They are based on estimated costs from manufacturers. Electrodialysis supplies range in cost from $0.20 to $0.30 per 3.8 m^3 (1000 gal), depending on plant size. Reverse osmosis supplies range in cost from $0.20 to $0.50 per 3.8 m^3 (1000 gallons), depending on plant size.

Chemical costs are provided in Table 34 for various chemicals used in water treatment. These chemical costs are for January 1977 and should be trended as necessary by using the Wholesale Price Index as discussed previously.

Chemicals not listed in Table 34 include: granular activated carbon, regenerative chemicals for activated alumina, ion exchange softening and demineralization, and salt for sodium hypochlorite on-site generation. Costs for these chemicals are provided on cost curves.

Table 34

WATER TREATMENT CHEMICAL COSTS

Chemical	Packaging	Price
Activated Carbon (Powdered)	65 lb bags	1-14 bags, 44.45 cents per lb 15-28 bags, 41.95 cents per lb 29-50 bags, 39.45 cents per lb
Alum	100 lb bags	1-9 bags, $16 per bag 10-20 bags, $11 per bag 21-100 bags, $9.25 per bag
Calcium Hypochlorite	100 lb drums	$81.60 per drum
Chlorine	100 lb cylinders	1-9 cylinders, $30 per cylinder 10-24 cylinders, $26 per cylinder
Ferric Chloride	175 lb drums	0-630 lb, 18.65 cents per lb 631-12,000 lb, 17.90 cents per lb
Ferric Sulfate	100 lb bags	1 bag, $10.15 2-20 bags, $8.90 per bag 21-100 bags, $7.65 per bag
Hydrated Lime	50 lb bags	1-40 bags, $2.85 per bag 41-200 bags, $2.23 per bag
Polyphosphate (Sodium Hexameta)	100 lb bags	1-9 bags, $36.80 per bag 10-19 bags, $34.80 per bag
Polymer (Dry)	50 lb & 100 lb bags	varies, use $2.25 per lb
(Wet)	55 gallon drums	varies, use $0.30 per lb
Potassium Permanganate	110 lb bags 550 lb bags	92.35 cents per lb 73.80 cents per lb

Refer to section VI C for an example of the development of annual operation and maintenance costs using the labor, power and supplies cost curves and the chemical cost table.

1. Unit Processes

Figures 34 through 75 are operation and maintenance cost curves for various water treatment unit processes. Before using these cost curves, the estimator should carefully review the following summaries of power requirements and chemical dosage rates or regeneration requirements used in developing the unit process operation and maintenance cost curves. In addition, the preceding introductory material should be reviewed for general considerations regarding preparation of labor, power and supplies cost curves and Table 34, Water Treatment Chemical Costs.

If local conditions dictate use of different design requirements, the operation and maintenance cost curves must be revised accordingly.

a. **Mechanical Draft Aeration.** Operation and maintenance cost curves developed for mechanical draft aeration include power and supplies, which are presented on Figure 36. Power requirements are based on the blower motor horsepower and 24 hour per day operation.

b. **Diffused Aeration.** Operation and maintenance cost curves for diffused aeration include power requirements and supplies, as shown on Figure 37. Power requirements are based on the compressor motor horsepower and 24 hour per day use.

c. **Activated Carbon Beds.** Included in the operation and maintenance cost curves for activated carbon beds are power, equipment supplies, and enclosure supplies. These three cost curves are presented on Figure 38. An activated carbon media replacement cost curve is presented on Figure 39. Power costs are based on the backwash pump and surface wash pump motor horsepower requirements and their use for one hour each day. The media replacement cost curve is based on shipment of spent carbon to a custom regeneration facility. Assumed transport distance and regeneration interval are 1610 km (1000 miles), one-way, and 6 months, respectively. Included in the media replacement cost curve are freight, regeneration and replacement of media lost during shipping and/or regeneration. Necessary labor was assumed provided by the water treatment facility, therefore no additional cost was included.

d. **Activated Alumina Columns.** Operation and maintenance cost curves for activated alumina include power, equipment supplies and enclosure supplies, which are presented on Figure 40. A regenerative chemical cost curve is also presented for activated alumina columns on Figure 41. Power requirements are based on the total motor horsepower for surface wash pump, backwash pump, chemical feed pumps, and chemical mixer. Use of the backwash and surface wash pumps is estimated at one hour each day and the chemical feed pumps and mixer are estimated for use once every six days for 2 hours. The regenerative chemical cost curve includes cost for sodium hydroxide and sulfuric acid. Available information indicates that activated alumina material must be replaced every 2 to 5 years.

e. **Rapid Mix**. Rapid mix operation and maintenance cost curves include power and equipment supplies and are shown on Figure 42. Power requirements are based on the flash mixer motor horsepower and 24 hour per day operation.

f. **Flocculation**. Operation and maintenance cost curves developed for flocculation include power and supplies and are shown on Figure 43. Power requirements are based on the turbine flocculator motor horsepower and 24 hour per day use.

g. **Sedimentation**. Operation and maintenance cost curves developed for the sedimentation process include a cost curve for power and one for supplies as shown on Figure 44. The power cost curve is based on the horsepower requirement of the sludge collector motor and 24 hour per day operation.

h. **Flocculator-Clarifier**. Developed for the flocculator-clarifier are operation and maintenance cost curves for power and supplies. These two cost curves are shown on Figure 45. Power costs are based on sludge collector motor horsepower, turbine flocculator motor horsepower, and 24 hour per day operation.

i. **Ion Exchange Softening**. Ion exchange softening operation and maintenance cost curves include curves for power, equipment supplies and enclosure supplies, which are shown on Figure 46. A regenerative chemical cost curve is provided for ion exchange softening on Figure 47. Power requirements are based on the total motor horsepower for backwash pump and chemical mixer. Use of this equipment is estimated at one hour per day. The regenerative chemical cost curve is based on equipment manufacturer's stated salt requirements.

j. Pressure Filtration. Operation and maintenance cost curves for pressure filtration include power, equipment supplies, and enclosure supplies cost curves for surface loading rates of 120, 240 and 360 m^3/m^2/day (2, 4 and 6 gpm/ft^2). Figures 48 and 49 include these nine cost curves. Power costs are based on backwash pump motor horsepower, surface wash pump motor horsepower and equipment use one hour each day.

k. Gravity Filtration. Gravity filtration operation and maintenance cost curves include power, equipment supplies and enclosure supplies cost curves for surface loading rates of 120, 240 and 360 m^3/m^2/day (2, 4 and 6 gpm/ft^2). These nine cost curves are presented on Figures 50 and 51. Power costs are based on motor horsepower requirements for backwash pump, surface wash pump, and equipment use for one hour each day.

l. Demineralization. Operation and maintenance cost curves for demineralization include power, equipment supplies, enclosure supplies, and regenerative chemicals. These curves are shown on Figure 52 and Figure 53.

Power requirements are based on the total motor horsepower for backwash pump, chemical feed pumps and on use of each of these pumps one hour each day for systems less than 380 m^3/day (0.1 mgd) and three hours each day for systems greater than 380 m^3/day (0.1 mgd). The regenerative chemical cost curve is based on costs for caustic soda and sulfuric acid.

m. Electrodialysis. Operation and maintenance cost curves developed for the electrodialysis unit process include power, equipment supplies and enclosure supplies. Power and equipment supplies cost curves are presented on Figure 54. Power costs are based on power requirements for the electrodialysis process equipment, feed pump motor, brine recirculation pump motor and chemical cleaning equipment. Power costs are based on 3 kWh per m^3 (11 kWh per 1000 gal) and equipment supplies costs include membrane and cartridge filter replacements plus cleaning chemicals. Figure 55 includes the enclosure supplies cost curve.

n. Reverse Osmosis. Reverse osmosis operation and maintenance cost curves include power, equipment supplies and enclosure supplies. Figure 56 includes the power and equipment supplies cost curves. Power costs are based on 3 kWh per m^3 (11 kWh per 1000 gal) and equipment supplies costs include membrane and cartridge filter replacements along with necessary chemicals. The enclosure supplies cost curve is presented on Figure 57.

o. **Chemical Feed.** Operation and maintenance cost curves for chemical feed systems include power, equipment supplies and enclosure supplies for various chemical dosages. Summarized in Table 35 are the chemical feed systems and their appropriate cost curve figure numbers.

Table 35

SUMMARY OF CHEMICAL FEED SYSTEM OPERATION AND MAINTENANCE COST CURVES

Chemical Feed System	Dosages (mg/l)	Figure Numbers
Powdered Activated Carbon	50 or less	58
Coagulant	50 or less	59
Hydrated Lime	50 or less, 100 & 200	60, 61
Polymer	0.5, 1, 3 & 5	62, 63
Polyphosphate	5 or less	64
Chlorine	5 or less & 10	65
Ozone	1.5, 5 & 10	66, 67
Calcium Hypochlorite	1.5, 5 & 10	68, 69
Sodium Hypochlorite	1.5, 5 & 10	70, 71
Sodium Hypochlorite (on-site generation)	1.5, 5 & 10	72, 73

Power costs are based on necessary feeders, agitators, mixers, and metering pumps and 24 hour per day operation. In addition to the chemical feed costs previously discussed, cost curves for ozone and sodium hypochlorite (on-site generation) include the following operation and maintenance costs: power for chemical generation and supplies for the generating equipment and enclosure.

Ozone power requirements are based on 26 kWh per kg (12 kWh per lb) of ozone produced. Power requirements for on-site production of sodium hypochlorite are based on 10 kWh per kg (4.6 kWh per lb) of chlorine produced. Ozone and sodium hypochlorite production is based on a flow rate of 70 per cent of plant capacity. The salt requirement for sodium hypochlorite production is 4.7 kg per kg (4.7 lb per lb) of chlorine produced.

2. Laboratory Facilities

Laboratory costs depend on type and frequency of analyses and type and condition of testing equipment. Laboratory operation and maintenance costs should be determined for each local water treatment situation. Therefore, these costs are not presented in this report.

3. Waste Disposal Facilities

The operation and maintenance cost curve for lagoons is based on waste solids removal by contract. This cost is related to the total solids produced using an alum dosage of 30 mg/l and a turbidity removal of 50 JTU. The lagoon sludge removal cost curve is shown on Figure 74.

4. Package Plants

Package plant operation and maintenance cost curves include power, equipment supplies and enclosure supplies as shown on Figure 75. Power requirements are based on the total motor horsepower for the flash mixer, mechanical flocculator, effluent, backwash and chemical feed pumps, and the chemical mixers. Power costs include equipment use 24 hours per day.

5. Upgrading Existing Facilities

Operation and maintenance cost curves corresponding to the various upgrading methods described in section V have been discussed previously. Cost curves are not presented for replacement of filter media, chemical change, improvement of hydraulic conditions, operator training, monitoring, or control. These are best determined for each water treatment situation. Cost curves for tube settlers are not included as this upgrading method generally does not create additional operation or maintenance costs.

C. COST DATA EXAMPLES

Three examples have been prepared which illustrate use of the cost data in this report. Examples No. 1 and 2 develop capital and operation and maintenance costs for conventional facilities; Example No. 3 develops similar costs for a package plant. As Examples No. 2 and 3 are for facilities with equal capacity, a comparison of costs for a conventional facility versus costs for a package plant can be made.

1. Example No. 1

The following example is based on treatment of a surface water for turbidity removal in a 3,000 m^3/day (0.8 mgd) enclosed conventional plant with the following unit processes:

Rapid Mix
Flocculation
Sedimentation
Filtration–gravity with 240 m^3/m^2/day (4 gpm/ft^2) rate
Coagulation Feed–alum–20 mg/l
Polymer Feed–dry–0.5 mg/l
Chlorine Feed–gas–5 mg/l
Lagoons
Laboratory

a. **Capital Cost** – 3,000 m^3/day (0.8 mgd) Conventional Facility.

Rapid Mix (Figure 9)	$ 21,000
Flocculation (Figure 10)	60,000
Sedimentation (Figure 11)	275,000
Filtration–Process (Figure 15)	105,000
Filtration–Enclosure (Figure 15)	17,000
Coagulant Feed–Process (Figure 22)	15,000
Coagulant Feed–Enclosure (Figure 22)	3,700
Polymer Feed–Process (Figure 24)	7,400
Polymer Feed–Enclosure (Figure 24)	3,700
Chlorine Feed–Process (Figure 26)	7,000
Chlorine Feed–Enclosure (Figure 26)	3,700
Lagoons (Figure 31)	9,000
Laboratory (Section IV, B, 2)	7,000
Total	$534,500

An economic evaluation of proposed facilities should include a comparison of either the present worth or the annual cost of the alternatives. It is common practice in the water industry to use annual costs for judging alternatives. For purposes of this report, a plant service life of 30 years and an interest rate of 8 per cent have been assumed. To determine the equivalent annual cost for repayment of the capital cost, multiply the capital cost by the appropriate capital recovery factor, as follows:

Annual Capital Cost =

Capital Recovery Factor (30 yrs @ 8%) x Total Capital Cost =

0.0883 x $534,500

Annual Capital Cost = $47,480

Listed in Table 36 are additional capital recovery factors for various interest rates.

Table 36

CAPITAL RECOVERY FACTORS*

	Capital Recovery Factor			
Year	**i=6%**	**i=8%**	**i=10%**	**i=12%**
1	1.060 00	1.080 00	1.100 00	1.120 00
2	0.545 44	0.560 77	0.576 19	0.591 70
3	0.374 11	0.388 03	0.402 11	0.416 35
4	0.288 59	0.301 92	0.315 47	0.329 23
5	0.237 40	0.250 46	0.263 80	0.277 41
6	0.203 36	0.216 32	0.229 61	0.243 23
7	0.179 14	0.192 07	0.205 41	0.219 12
8	0.161 04	0.174 01	0.187 44	0.201 30
9	0.147 02	0.160 08	0.173 64	0.187 68
10	0.135 87	0.149 03	0.162 75	0.176 98
11	0.126 79	0.140 08	0.153 96	0.168 42
12	0.119 28	0.132 70	0.146 76	0.161 44
13	0.112 96	0.126 52	0.140 78	0.155 68
14	0.107 58	0.121 30	0.135 75	0.150 87
15	0.102 96	0.116 83	0.131 47	0.146 82
16	0.098 95	0.112 98	0.127 82	0.143 39
17	0.095 44	0.109 63	0.124 66	0.140 46
18	0.092 36	0.106 70	0.121 93	0.137 94
19	0.089 62	0.104 13	0.119 55	0.135 76
20	0.087 18	0.101 85	0.117 46	0.133 88
21	0.085 00	0.099 83	0.115 62	0.132 24
22	0.083 05	0.098 03	0.114 01	0.130 81
23	0.081 28	0.096 42	0.112 57	0.129 56
24	0.079 68	0.094 98	0.111 30	0.128 46
25	0.078 23	0.093 68	0.110 17	0.127 50
26	0.076 90	0.092 51	0.109 16	0.126 65
27	0.075 70	0.091 45	0.108 26	0.125 90
28	0.074 59	0.090 49	0.107 45	0.125 24
29	0.073 58	0.089 62	0.106 73	0.124 66
30	0.072 65	0.088 83	0.106 08	0.124 14

*E. L. Grant and W. G. Ireson, "Principles of Engineering Economy," 5th edition, Ronald Press, New York, 1970,

b. **Annual Operation and Maintenance Cost** – 3,000 m^3/day (0.8 mgd) Conventional Facility.

Rapid Mix–Power (Figure 42)	$ 690
Rapid Mix–Supplies (Figure 42)	270
Flocculation–Power (Figure 43)	340
Flocculation–Supplies (Figure 43)	500
Sedimentation–Power (Figure 44)	430
Sedimentation–Supplies (Figure 44)	340
Filtration–Power (Figure 50)	95
Filtration–Process Supplies (Figure 50)	380
Filtration–Enclosure Supplies (Figure 51)	305
Coagulant Feed–Power & Process Supplies (Figure 59)	220
Coagulant Feed–Enclosure Supplies (Figure 59)	70
Polymer Feed–Process Supplies (Figure 62)	120
Polymer Feed–Power (Figure 63)	170
Polymer Feed–Enclosure Supplies (Figure 63)	70
Chlorine Feed–Power (Figure 65)	40
Chlorine Feed–Process Supplies (Figure 65)	75
Chlorine Feed–Enclosure Supplies (Figure 65)	70
Lagoon (Figure 74)	3,700
Chemicals (based on a flow of 70% of capacity) (Table 34)	
Alum @ $11/bag	3,750
Chlorine @ $26/cylinder	2,195
Polymer @ $2.25/lb.	1,900
Labor - Plant Type 3 (Figure 35) (For "Plant Type" description see page VI-16)	69,000
Total	$84,730

Total Annual Cost =

Annual Capital Cost (pg VI-25) + Annual O&M Cost =

$47,480 + $84,730

Total Annual Cost = $132,210

Annual Cost per 1000 m^3 (average flow = 70% of capacity)

$$\frac{\$132,210}{(3)\ (365)\ (0.7)} = \$172 \text{ per } 1000 \text{ m}^3$$

Annual Cost per 1000 gal (average flow = 70% of capacity)

$$\frac{\$132,210}{(800)\ (365)\ (0.7)} = \$0.65 \text{ per } 1000 \text{ gal}$$

2. Example No. 2

The following example is based on treatment of a surface water for turbidity removal in a 1,100 m^3/day (0.3 mgd) enclosed conventional plant with the following unit processes:

Rapid Mix
Flocculation
Sedimentation
Filtration–gravity with 240 m^3/m^2/day (4 gpm/ft^2) rate
Coagulant Feed–alum–20 mg/l
Polymer Feed–dry–0.5 mg/l
Chlorine Feed–gas–5 mg/l
Lagoons
Laboratory

a. **Capital Cost** – 1,100 m^3/day (0.3 mgd) Conventional Facility.

Rapid Mix (Figure 9)	$ 19,000
Flocculation (Figure 10)	52,000
Sedimentation (Figure 11)	225,000
Filtration–Process (Figure 15)	92,000
Filtration–Enclosure (Figure 15)	14,000
Coagulant Feed–Process (Figure 22)	15,000
Coagulant Feed–Enclosure (Figure 22)	3,700
Polymer Feed–Process (Figure 24)	7,400
Polymer Feed–Enclosure (Figure 24)	3,700

Chlorine Feed–Process (Figure 26)	7,000
Chlorine Feed–Enclosure (Figure 26)	3,700
Lagoons (Figure 31)	5,000
Laboratory (Section IV, B, 2)	7,000
Total	$454,500

Annual Capital Cost =

Capital Recovery Factor (30 yrs @ 8%) x Total Capital Cost =

0.08883 x $454,500

Annual Capital Cost = $40,370

Refer to Example No. 1 for discussion of the method used for calculating annual capital cost.

Refer to Table 36 for additional capital recovery factors.

b. **Annual Operation and Maintenance Cost** – 1,100 m^3/day (0.3 mgd) Conventional Facility.

Rapid Mix–Power (Figure 42)	$ 420
Rapid Mix–Supplies (Figure 42)	240
Flocculation–Power (Figure 43)	300
Flocculation–Supplies (Figure 43)	450
Sedimentation–Power (Figure 44)	370
Sedimentation–Supplies (Figure 44)	300
Filtration–Power (Figure 50)	80
Filtration–Process Supplies (Figure 50)	300
Filtration–Enclosure Supplies (Figure 51)	170
Coagulant Feed–Power & Process Supplies (Figure 59)	220
Coagulant Feed–Enclosure Supplies (Figure 59)	70
Polymer Feed–Process Supplies (Figure 62)	120
Polymer Feed–Power (Figure 63)	170
Polymer Feed–Enclosure Supplies (Figure 63)	70

Chlorine Feed–Power (Figure 65)	40
Chlorine Feed–Process Supplies (Figure 65)	75
Chlorine Feed–Enclosure Supplies (Figure 65)	70
Lagoon (Figure 74)	1,800
Chemicals based on a flow of 70% of capacity) (Table 34)	
Alum @ \$11/bag	1,410
Chlorine @ \$30/cylinder	960
Polymer @ \$2.25/lb	720
Labor–Plant Type 3 (Figure 35) (For "Plant Type" description see page VI-16)	62,000
Total	\$70,355

Total Annual Cost =

Annual Capital Cost (pg VI-29) + Annual O&M Cost =

\$40,370 + \$70,355

Total Annual Cost = \$110,725

Annual Cost per 1000 m^3 (average flow = 70% of capacity)

$$\frac{\$110{,}725}{(1.1)\ (365)\ (0.7)} = \$394 \text{ per } 1000 \text{ m}^3$$

Annual Cost per 1000 gal (average flow = 70% of capacity)

$$\frac{\$110{,}725}{(300)\ (365)\ (0.7)} = \$1.44 \text{ per } 1000 \text{ gal}$$

3. Example No. 3

The following example is based on treatment of a surface water for turbidity removal in a 1,100 m^3/day (0.3 mgd) enclosed package plant with the following unit processes:

Rapid Mix
Flocculation
Sedimentation
Filtration–gravity
Coagulant Feed–alum–20 mg/l
Polymer Feed–dry–0.5 mg/l
Chlorine Feed–gas–5 mg/l
Lagoons
Laboratory

a. Capital Cost – 1,100 m^3/day (0.3 mgd) Package Plant.

Package Plant–Process (Figure 32)	$160,000
Package Plant–Enclosure (Figure 32)	37,000
Lagoons (Figure 31)	5,000
Laboratory (Section IV, B, 2)	7,000
Total	$209,000

Annual Capital Cost =

Capital Recovery Factor (30 yrs @ 8%) x Total Capital Cost =
0.08883 x $209,000

Annual Capital Cost = $18,560

Refer to Example No. 1 for a discussion of the method used for calculating annual capital cost. Refer to Table 36 for additional capital recovery factors.

b. **Annual Operation and Maintenance Cost** – 1,100 m^3/day (0.3 mgd) **Package Plant.**

Package Plant–Process (Figure 75)	$ 680
Package Plant–Power (Figure 75)	1,600
Package Plant–Enclosure (Figure 75)	600
Lagoon (Figure 74)	1,800
Chemicals (based on a flow of 70% of capacity) (Table 34)	
Alum @ $11/bag	1,410
Chlorine @ $30/cylinder	960
Polymer @ $2.25/lb.	720
Labor–Plant Type 2 (Figure 34) (For "Plant Type" description see page VI-16)	5,200
Total	$12,970

Total Annual Cost =

Annual Capital Cost (pg VI-31) + Annual O&M Cost =

$18,560 + $12,970

Total Annual Cost = $31,530

Annual Cost per 1000 m^3 (average flow = 70% of capacity)

$$\frac{\$31{,}530}{(1.1)\ (365)\ (0.7)} = \$112 \text{ per } 1000\ m^3$$

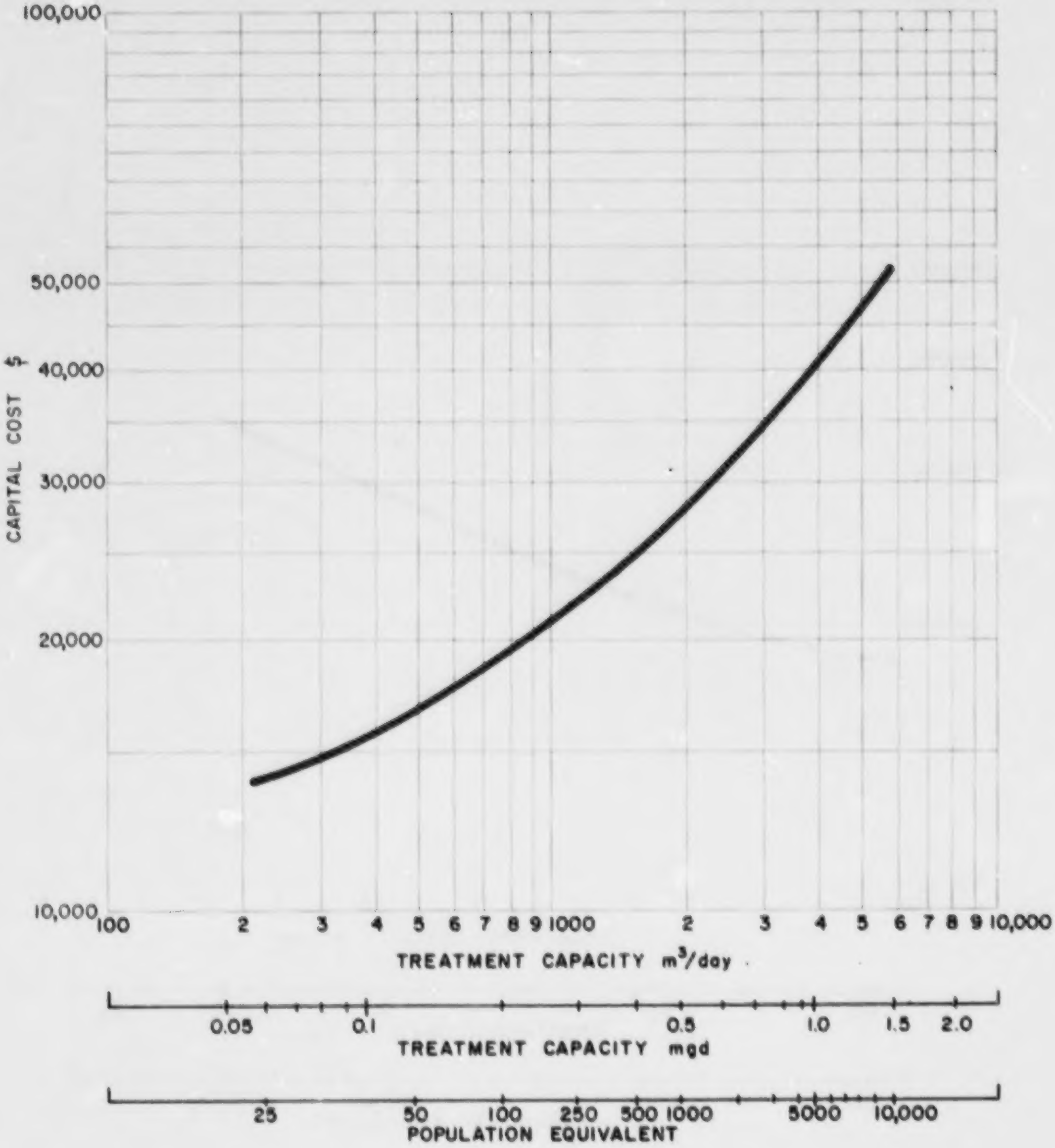
Annual Cost per 1000 gal (average flow = 70% of capacity)

$$\frac{\$31{,}530}{(300)\ (365)\ (0.7)} = \$0.41 \text{ per } 1000 \text{ gal}$$

Table 37

EXAMPLE COSTS SUMMARY

	Annual Cost	
	\$ per 1,000 m^3	\$ per 1,000 gal
Example No. 1 3,000 m^3/day (0.8 mgd) Conventional Facility	172	0.65
Example No. 2 1,100 m^3/day (0.3 mgd) Conventional Facility	394	1.44
Example No. 3 1,100 m^3/day (0.3 mgd) Package Plant	112	0.41

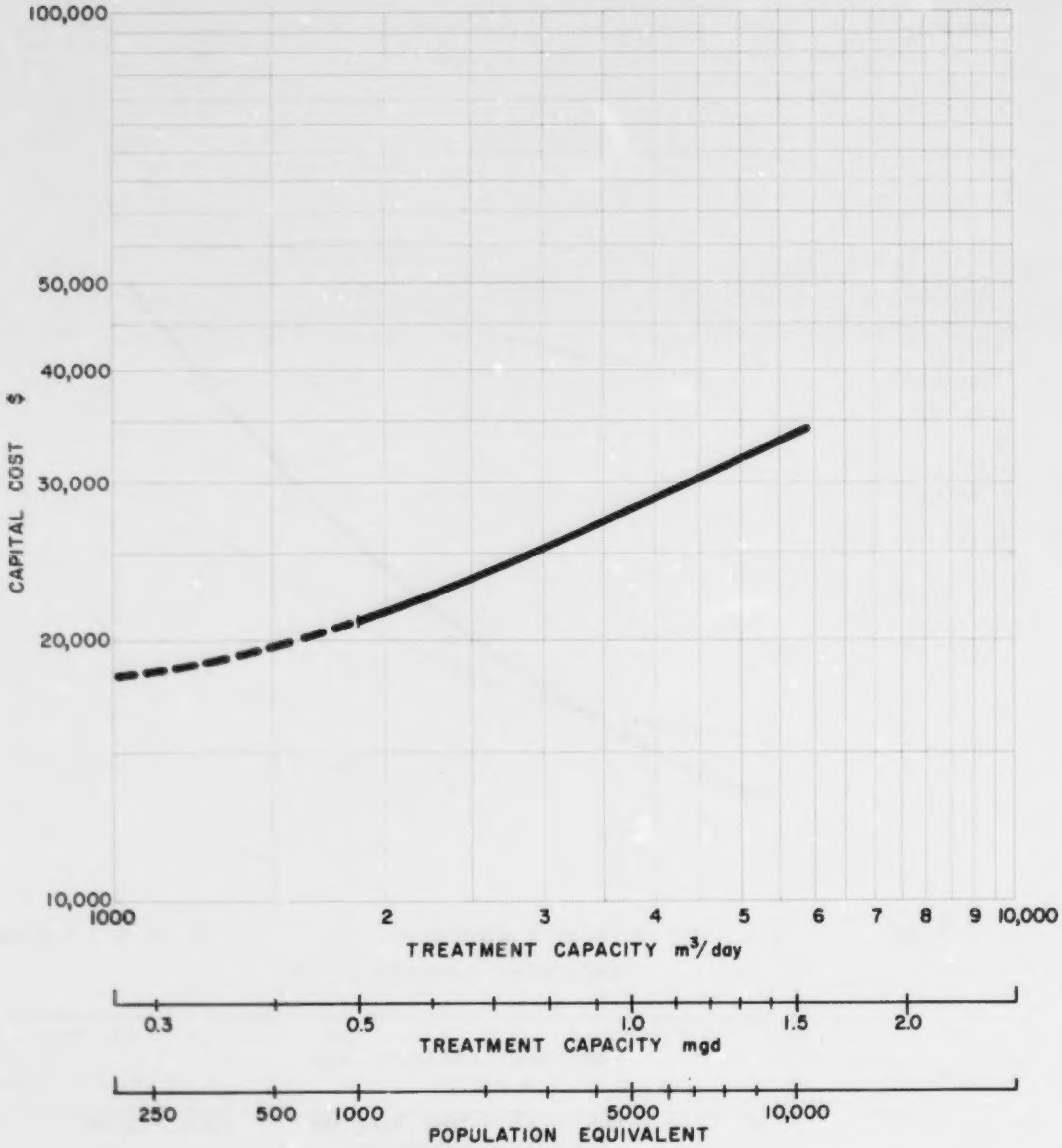


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- AERATION TOWER
- BLOWER & MOTOR
- BASIN & FOUNDATION
- PIPING, VALVES & CONTROLS
- FENCING

MECHANICAL AERATION
CAPITAL COST

FIGURE 5

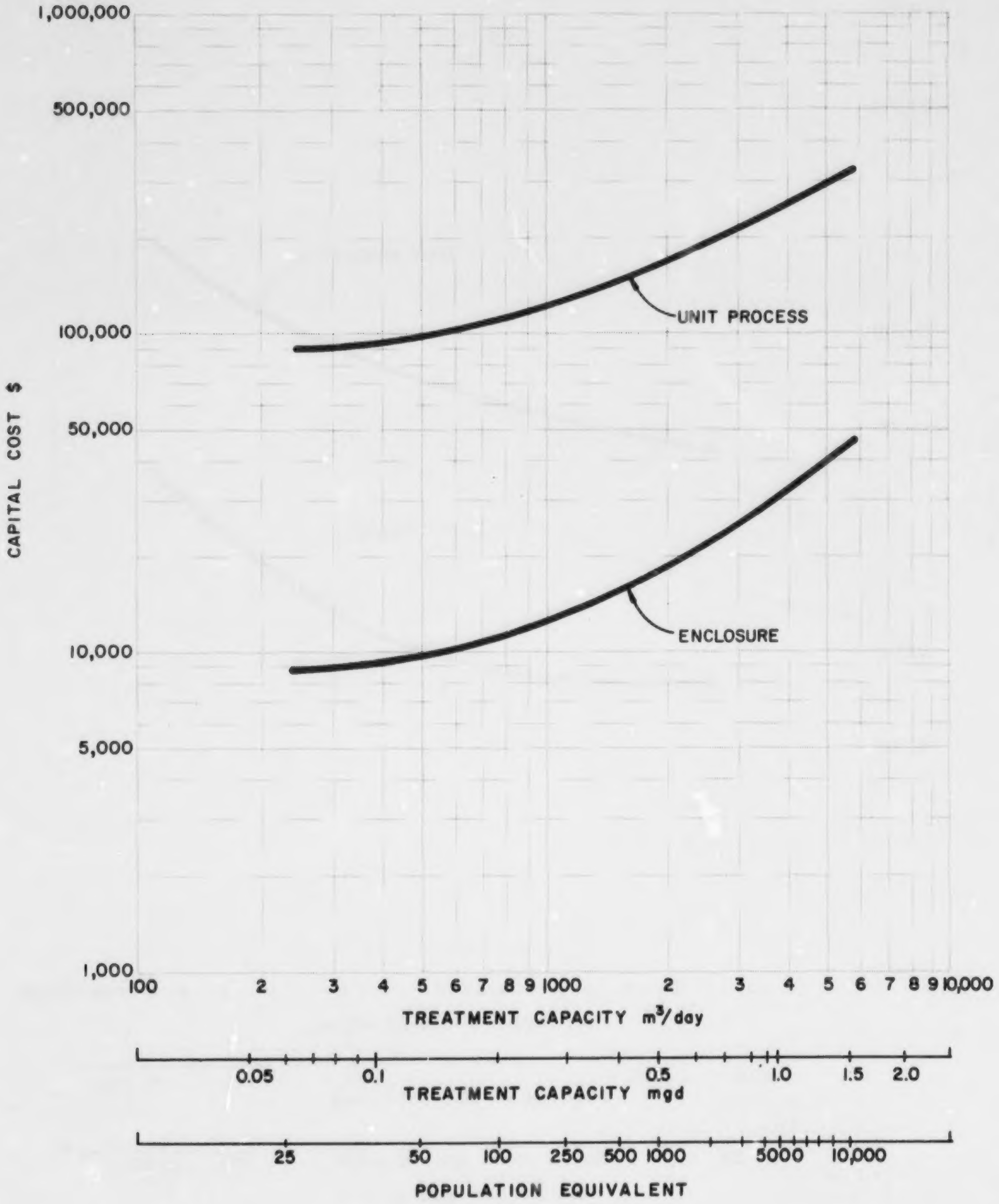


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- AERATION TANK & FOUNDATION
- COMPRESSOR & MOTOR
- AIR PIPING & DIFFUSERS
- INLET FILTER-SILENCER
- PIPING, VALVES & CONTROLS
- FENCING

DIFFUSED AERATION
CAPITAL COST

FIGURE 6



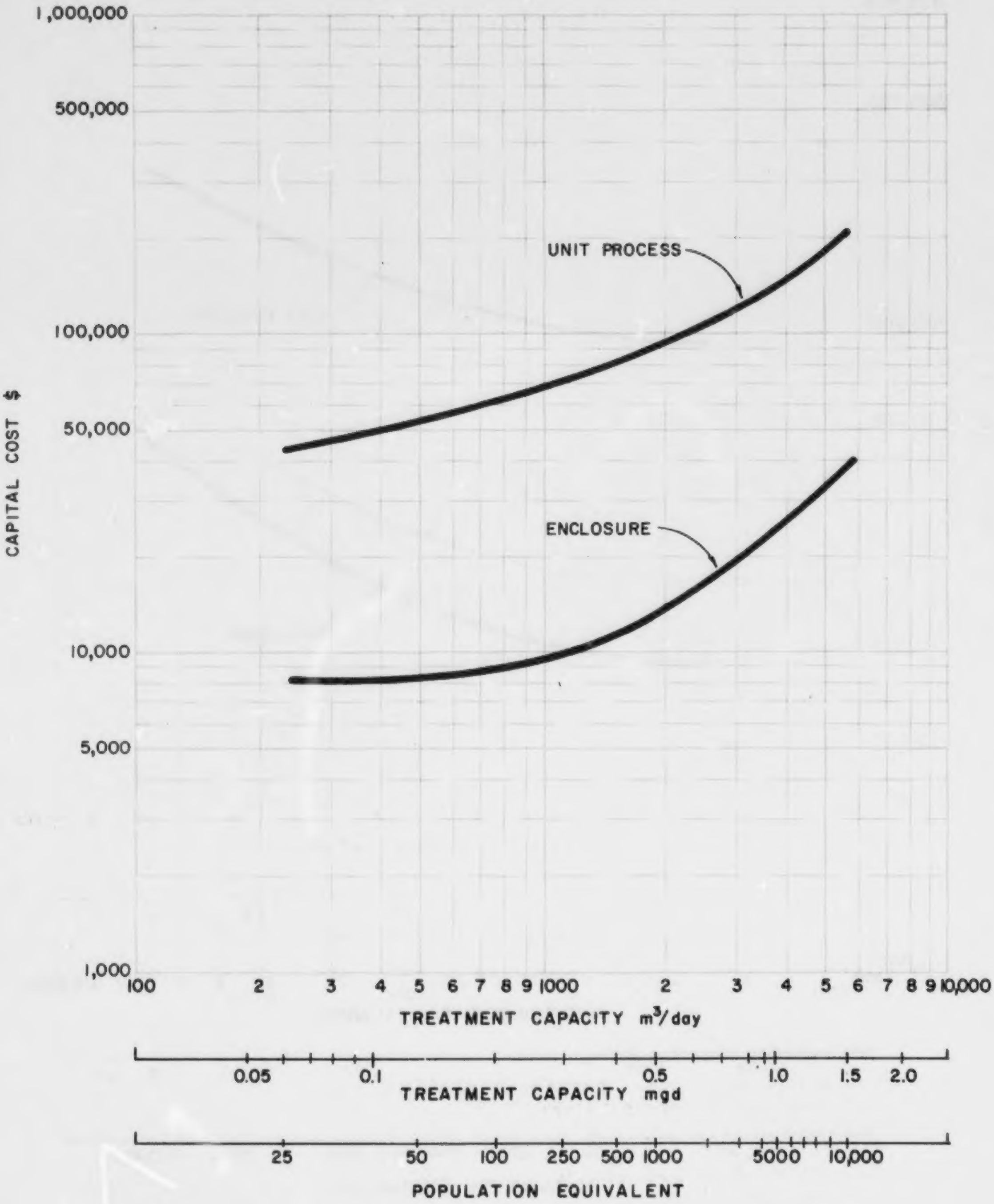
UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- ACTIVATED CARBON SHELL, UNDERDRAIN SYSTEM & MEDIA
- SURFACE WASH & BACKWASH SYSTEMS
- SPENT CARBON STORAGE TANK
- VALVES, PIPING & CONTROLS

ACTIVATED CARBON BED

CAPITAL COST

FIGURE 7

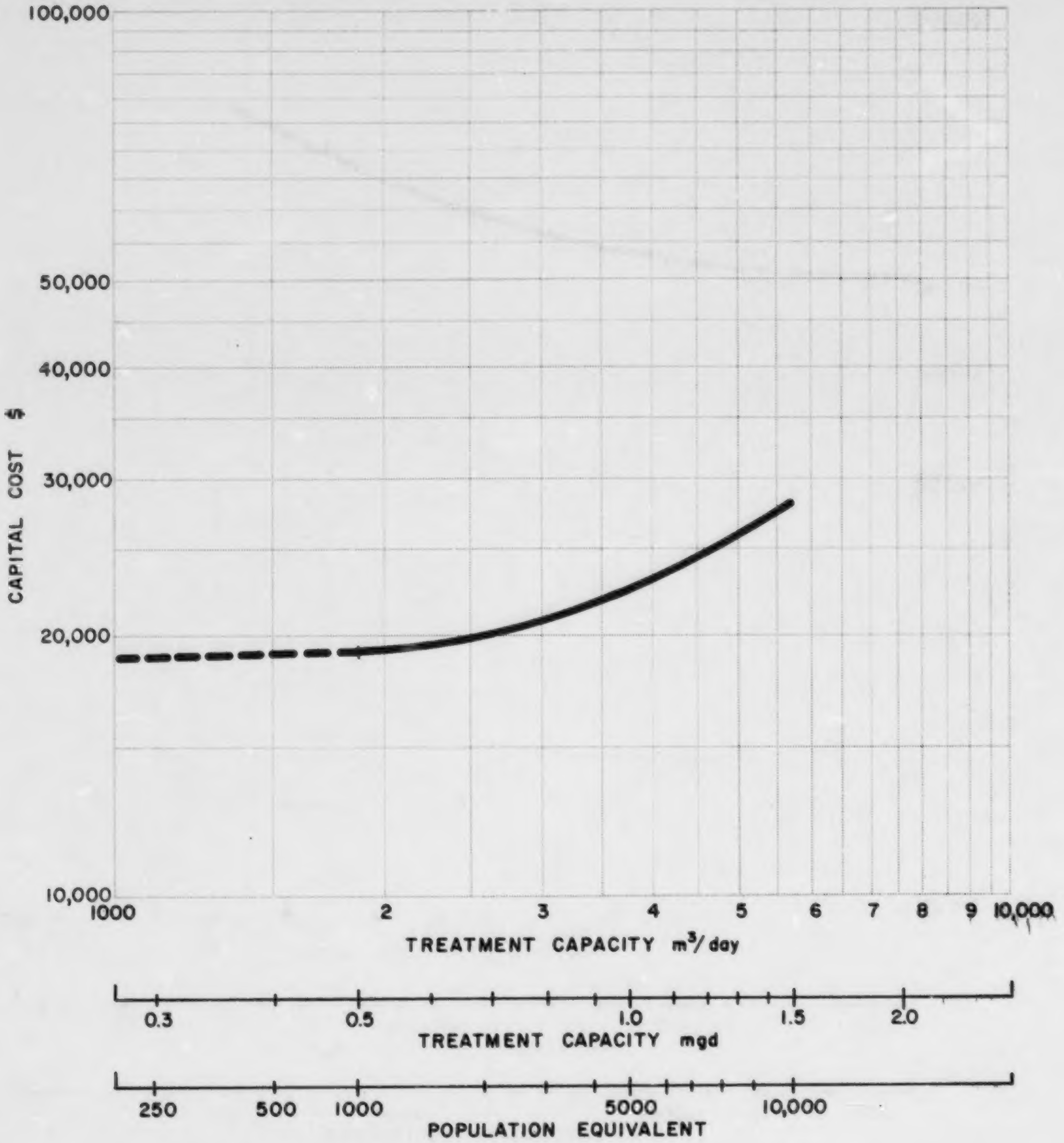


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- ACTIVATED ALUMINA COLUMN, UNDERDRAIN SYSTEM & MEDIA
- SURFACE WASH & BACKWASH SYSTEMS
- REGENERATION EQUIPMENT
- VALVES, PIPING & CONTROLS

ACTIVATED ALUMINA COLUMN
CAPITAL COST

FIGURE 8

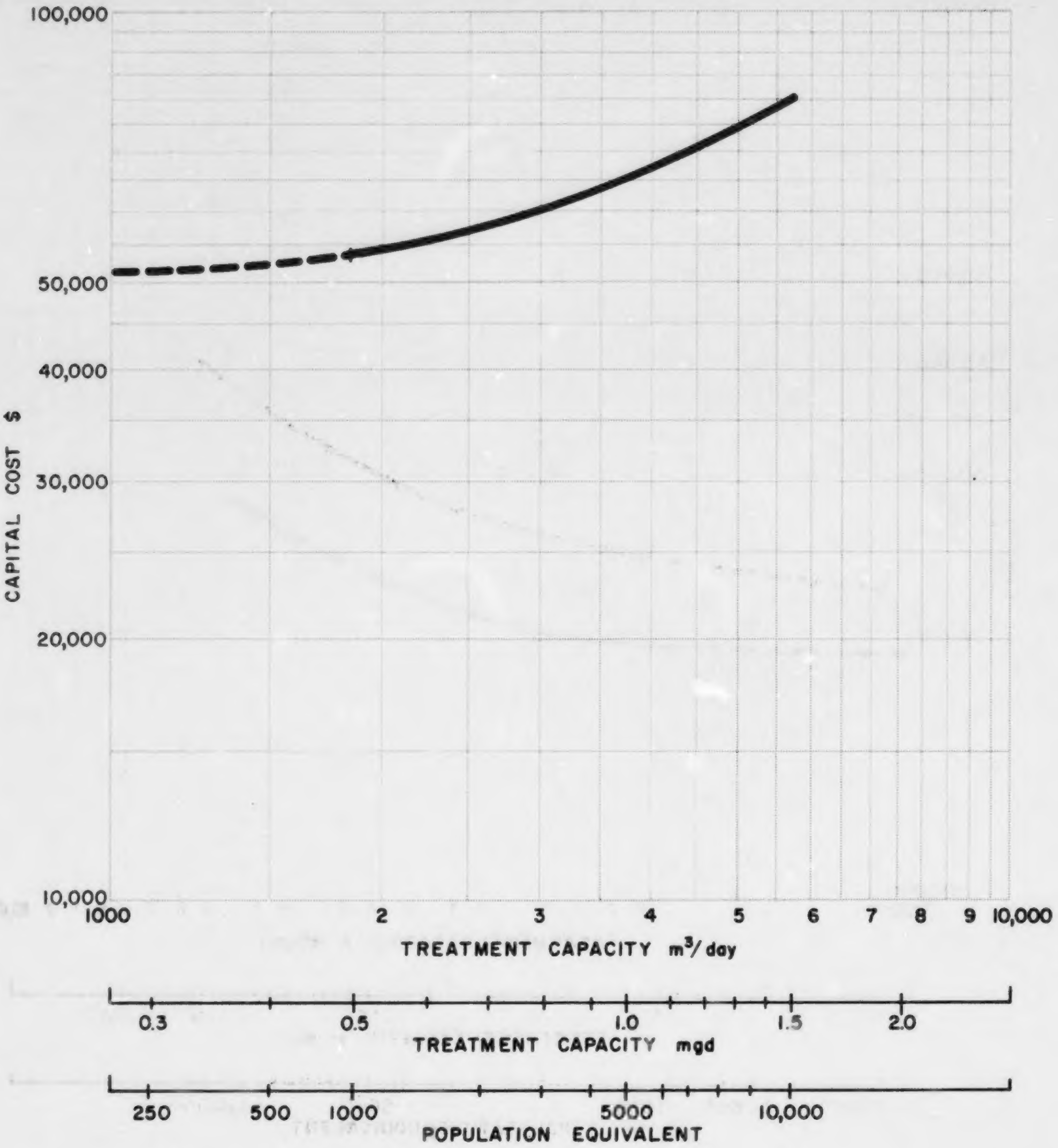


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- RAPID MIX BASIN & FOUNDATION
- FLASH MIXER
- BY-PASS PIPELINE WITH STATIC MIXER
- VALVES, PIPING & CONTROLS
- FENCING

RAPID MIX
CAPITAL COST

FIGURE 9

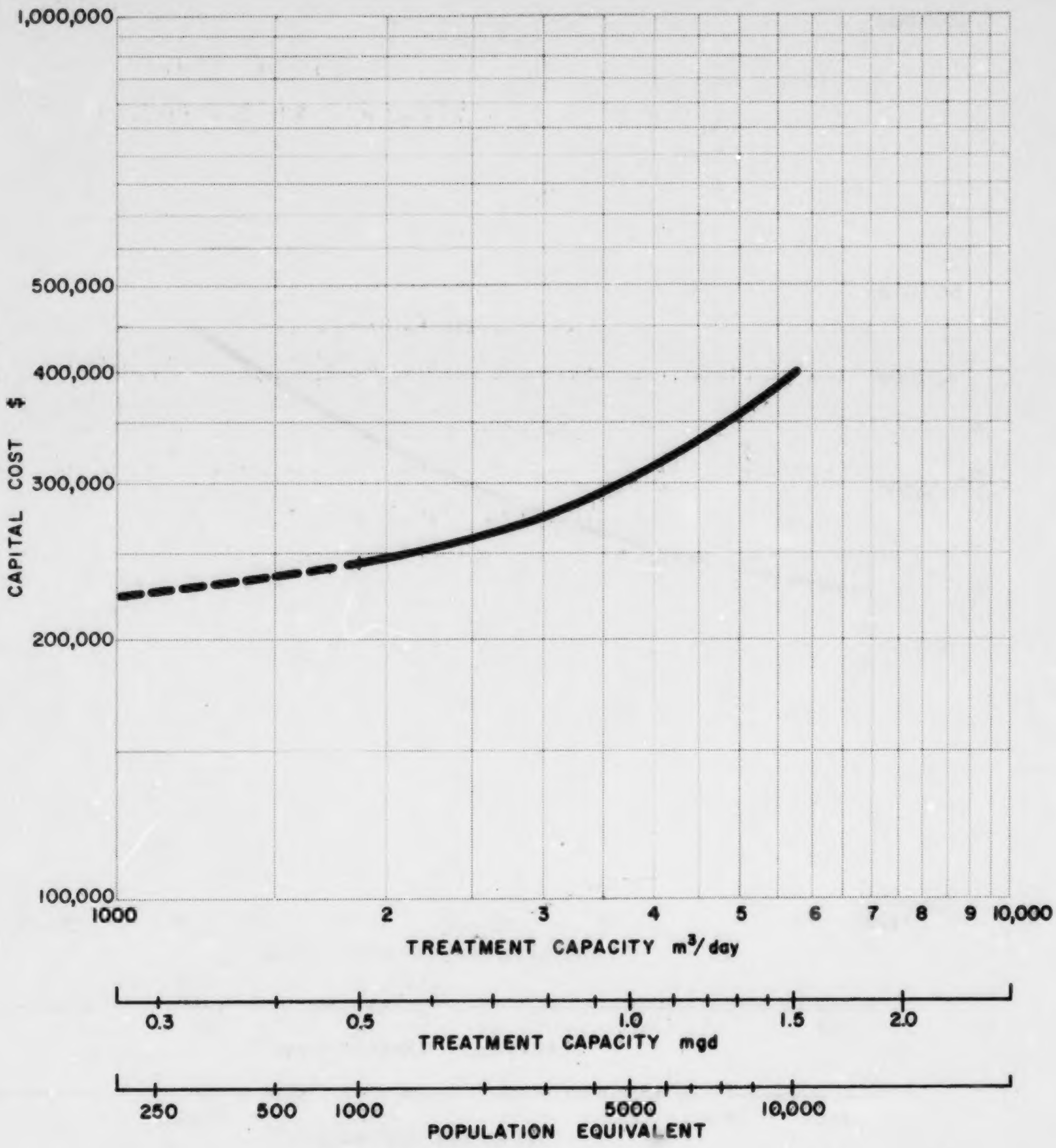


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- FLOCCULATION BASIN & FOUNDATION
- VERTICAL TURBINE FLOCCULATOR
- INLET & OUTLET DEVICES
- VALVES, PIPING & CONTROLS
- FENCING

FLOCCULATION
CAPITAL COST

FIGURE 10

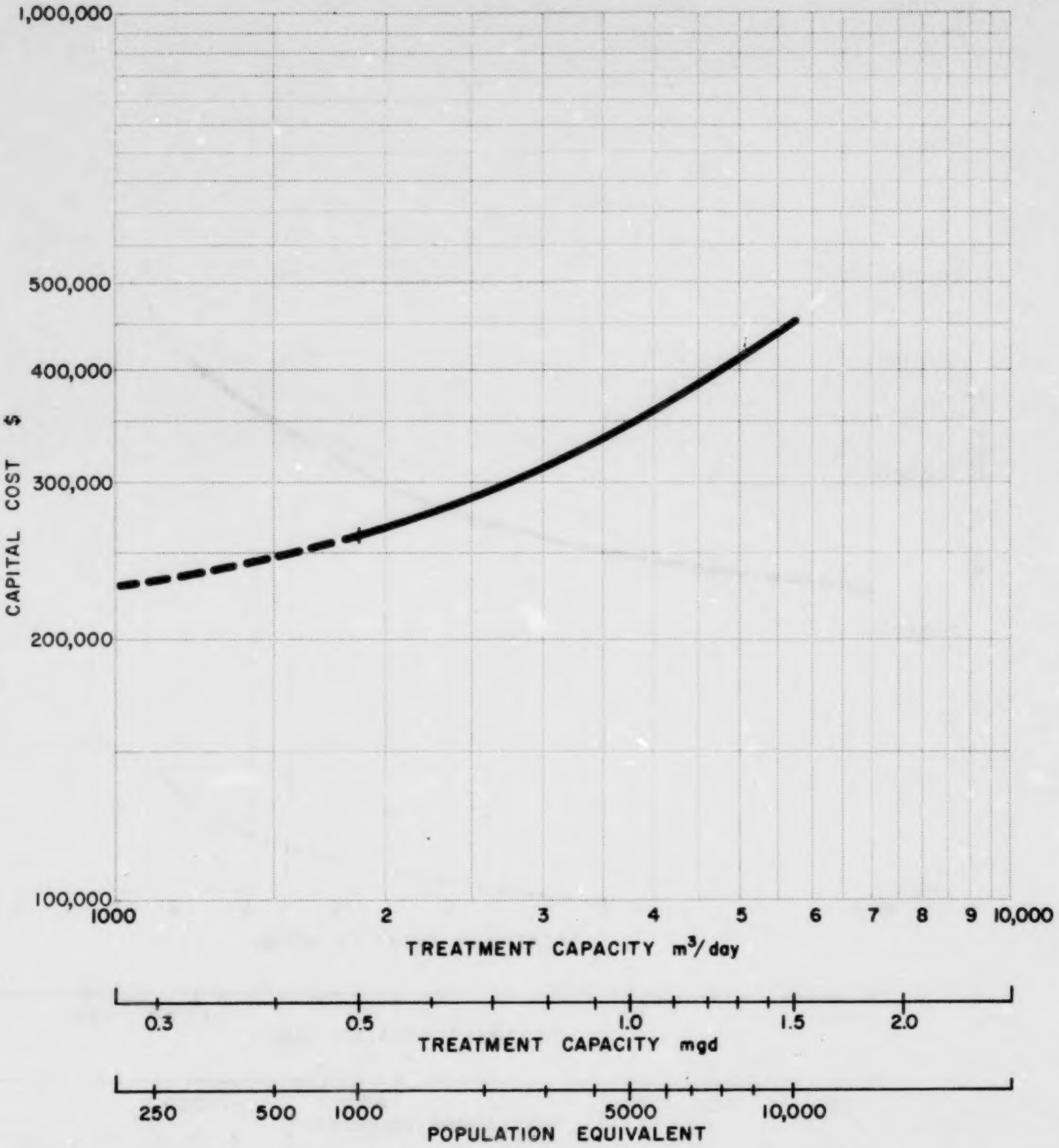


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- SEDIMENTATION BASIN & FOUNDATION
- WASTE SOLIDS COLLECTION EQUIPMENT
- INLET & OUTLET DEVICES
- VALVES, PIPING & CONTROLS
- FENCING

SEDIMENTATION
CAPITAL COST

FIGURE 11

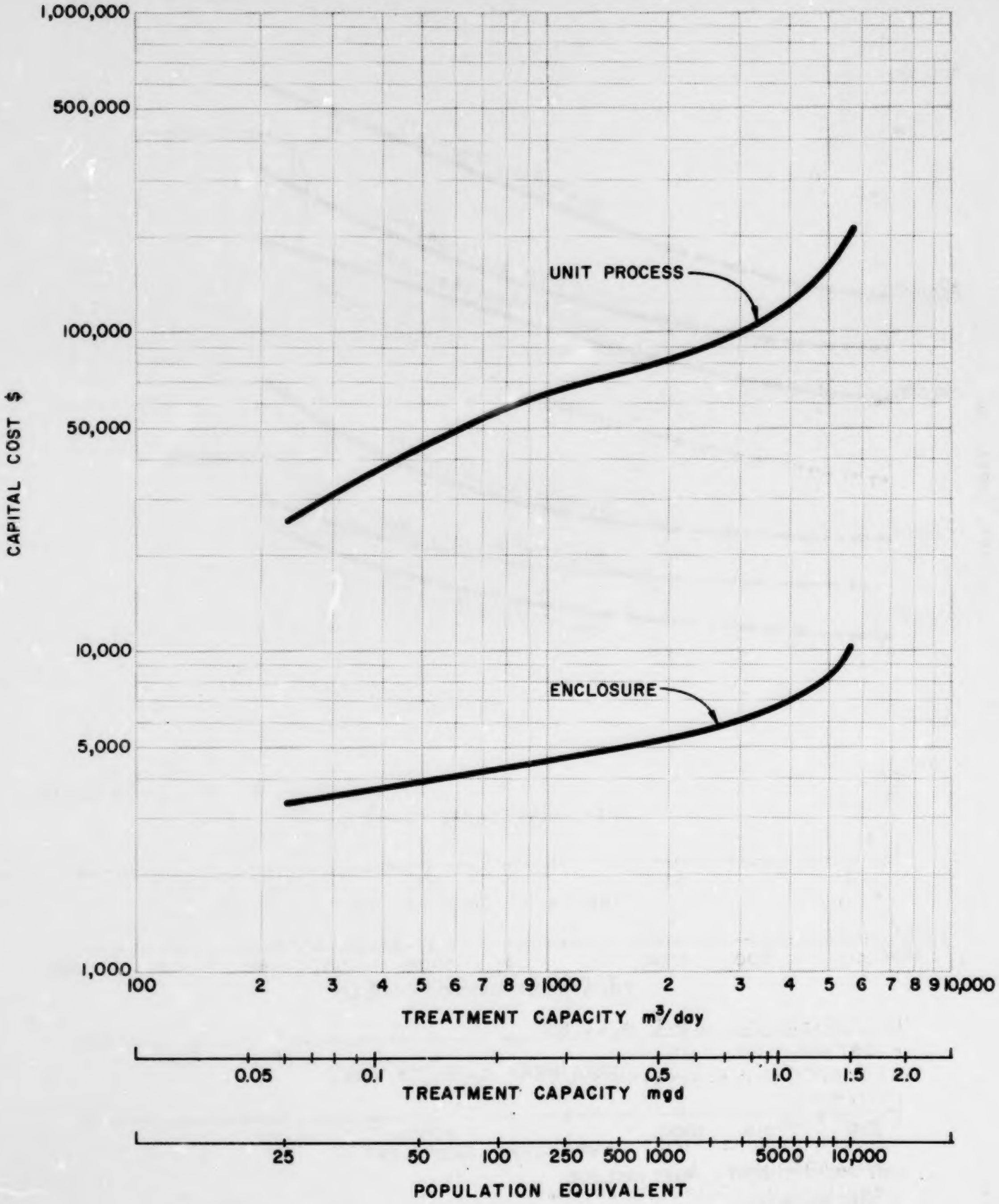


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- FLOCCULATOR-CLARIFIER BASIN & FOUNDATION
- WASTE SOLIDS COLLECTION EQUIPMENT
- VERTICAL TURBINE FLOCCULATOR
- INLET & OUTLET DEVICES
- VALVES, PIPING & CONTROLS
- FENCING

FLOCCULATOR-CLARIFIER
CAPITAL COST

FIGURE 12

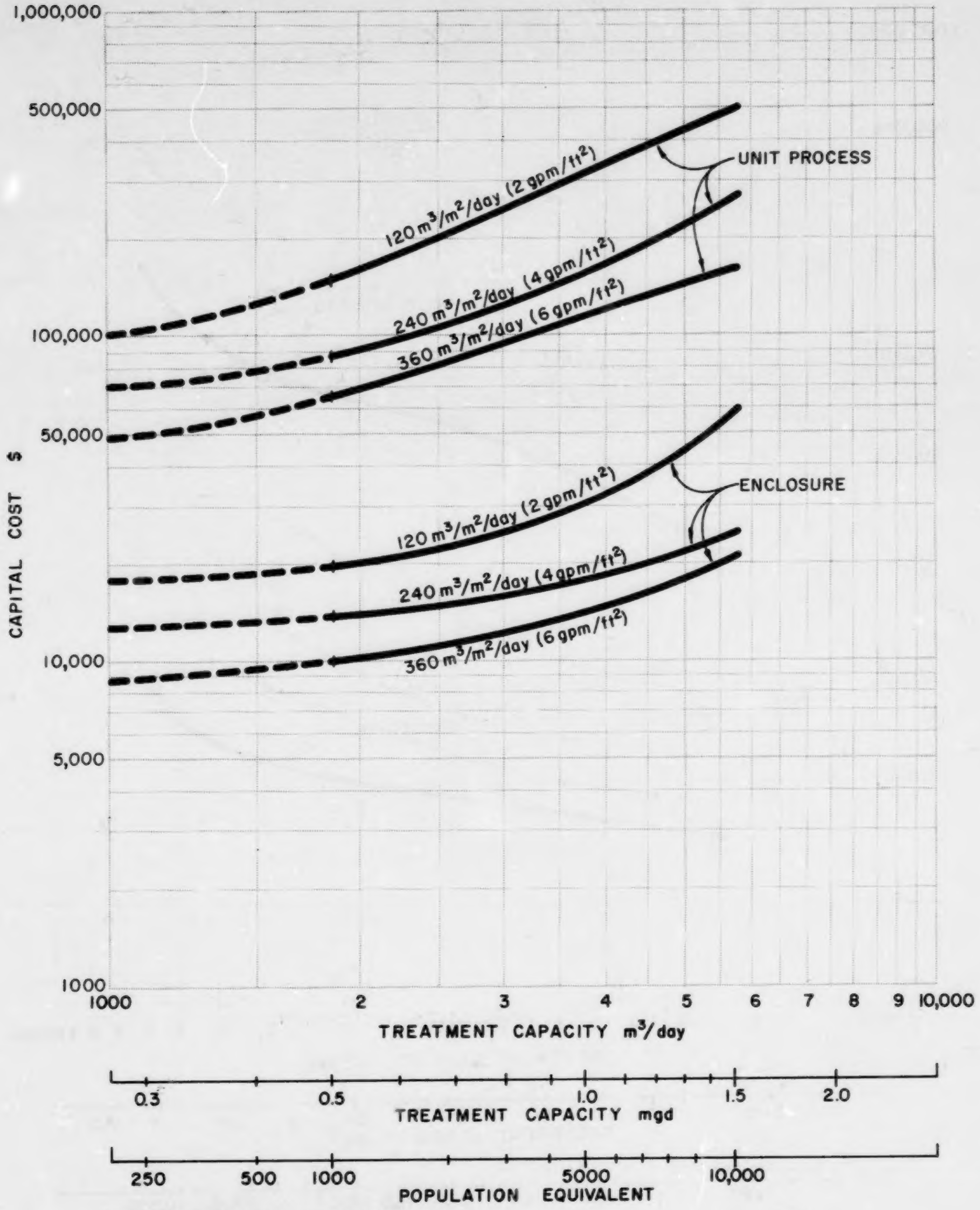


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- ION EXCHANGE SOFTENING SYSTEM
- CATION EXCHANGE RESIN
- REGENERATION EQUIPMENT
- VALVES, PIPING & CONTROLS
- BACKWASH SYSTEM

ION EXCHANGE SOFTENING
CAPITAL COST

FIGURE 13



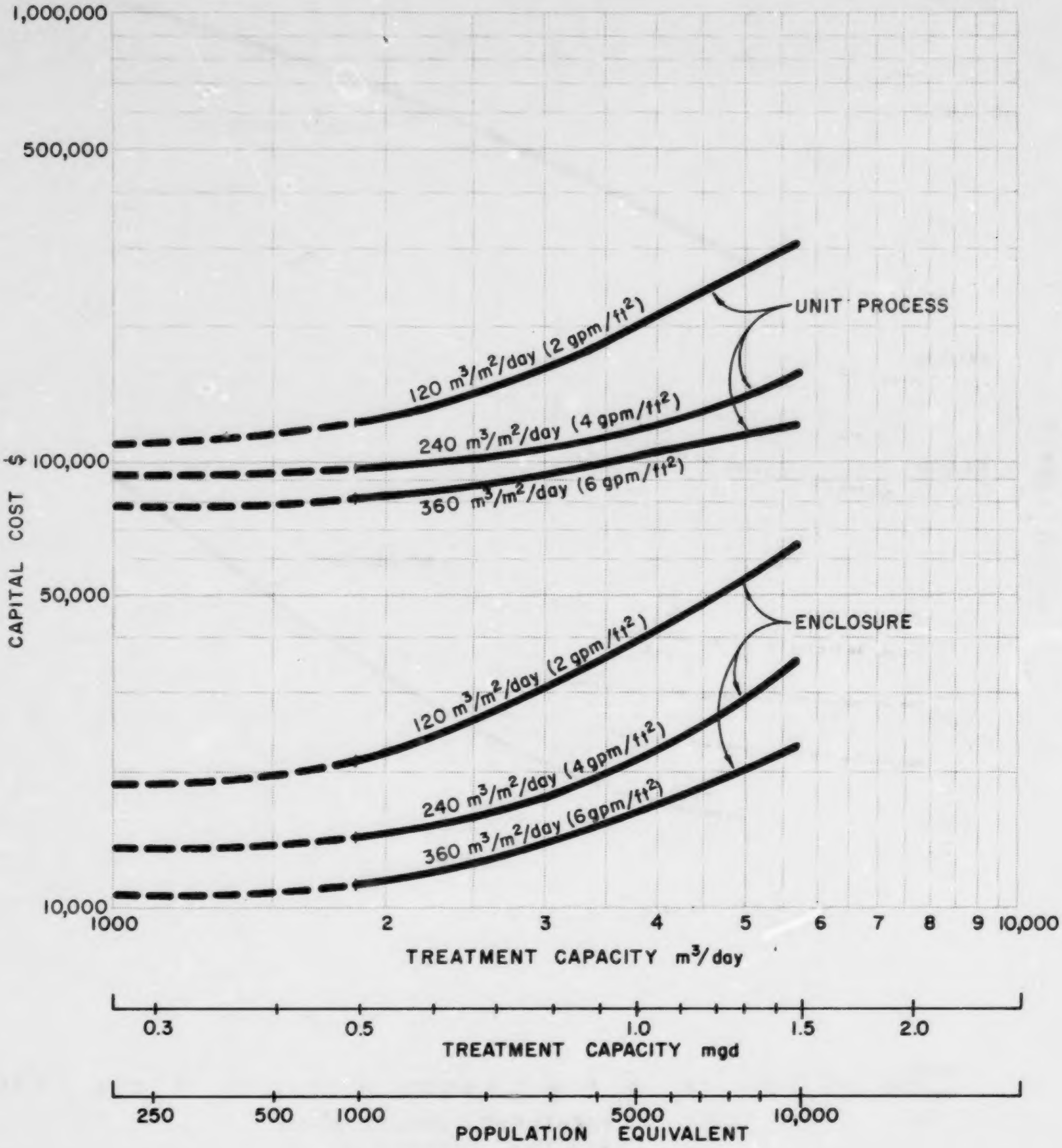
UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- PACKAGE PRESSURE FILTERS & MEDIA
- SURFACE WASH & BACKWASH SYSTEMS
- VALVES, PIPING & CONTROLS

PRESSURE FILTRATION

CAPITAL COST

FIGURE 14



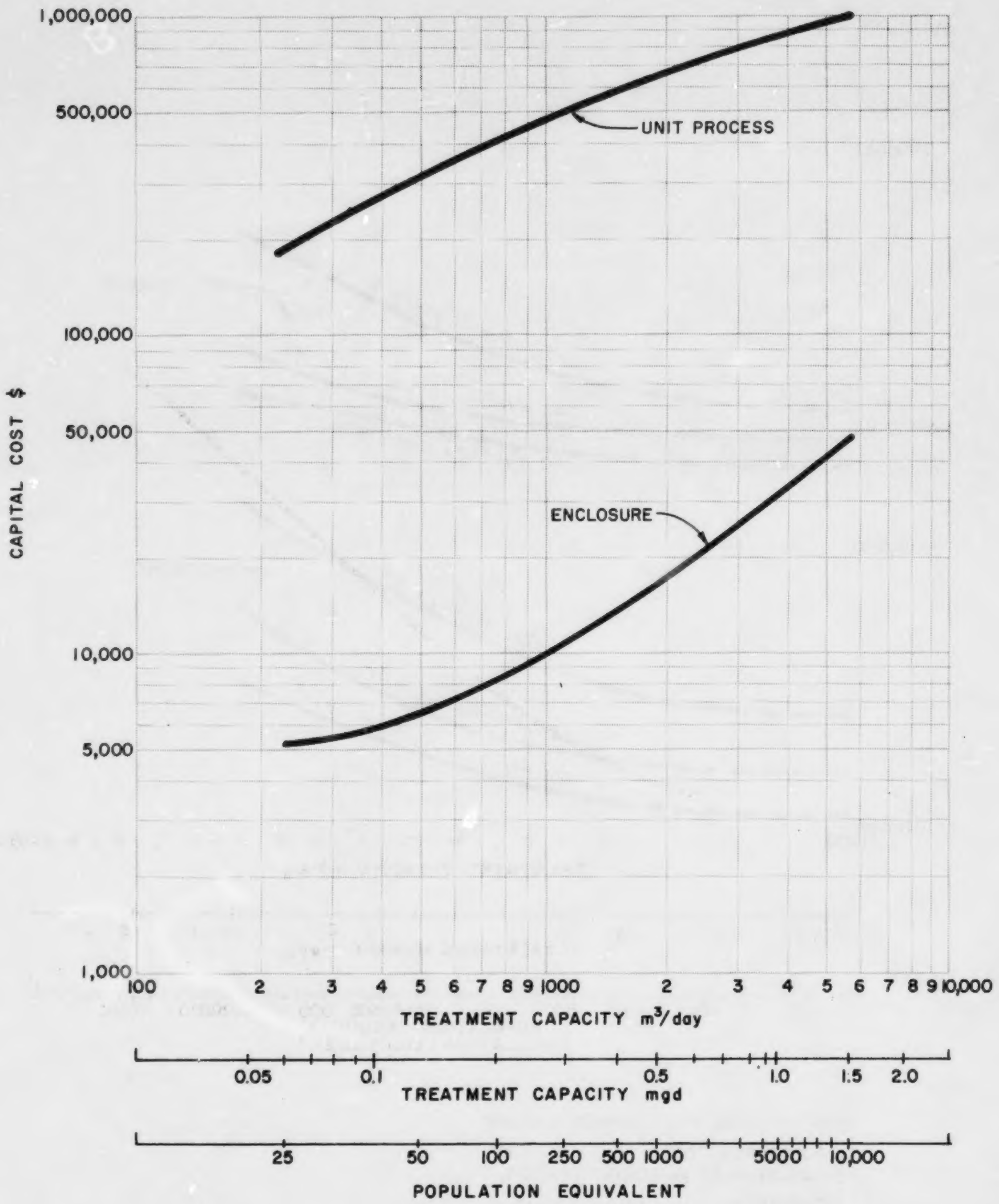
UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- PACKAGE GRAVITY FILTERS & MEDIA
- SURFACE WASH & BACKWASH SYSTEMS
- VALVES, PIPING & CONTROLS

GRAVITY FILTRATION

CAPITAL COST

FIGURE 15

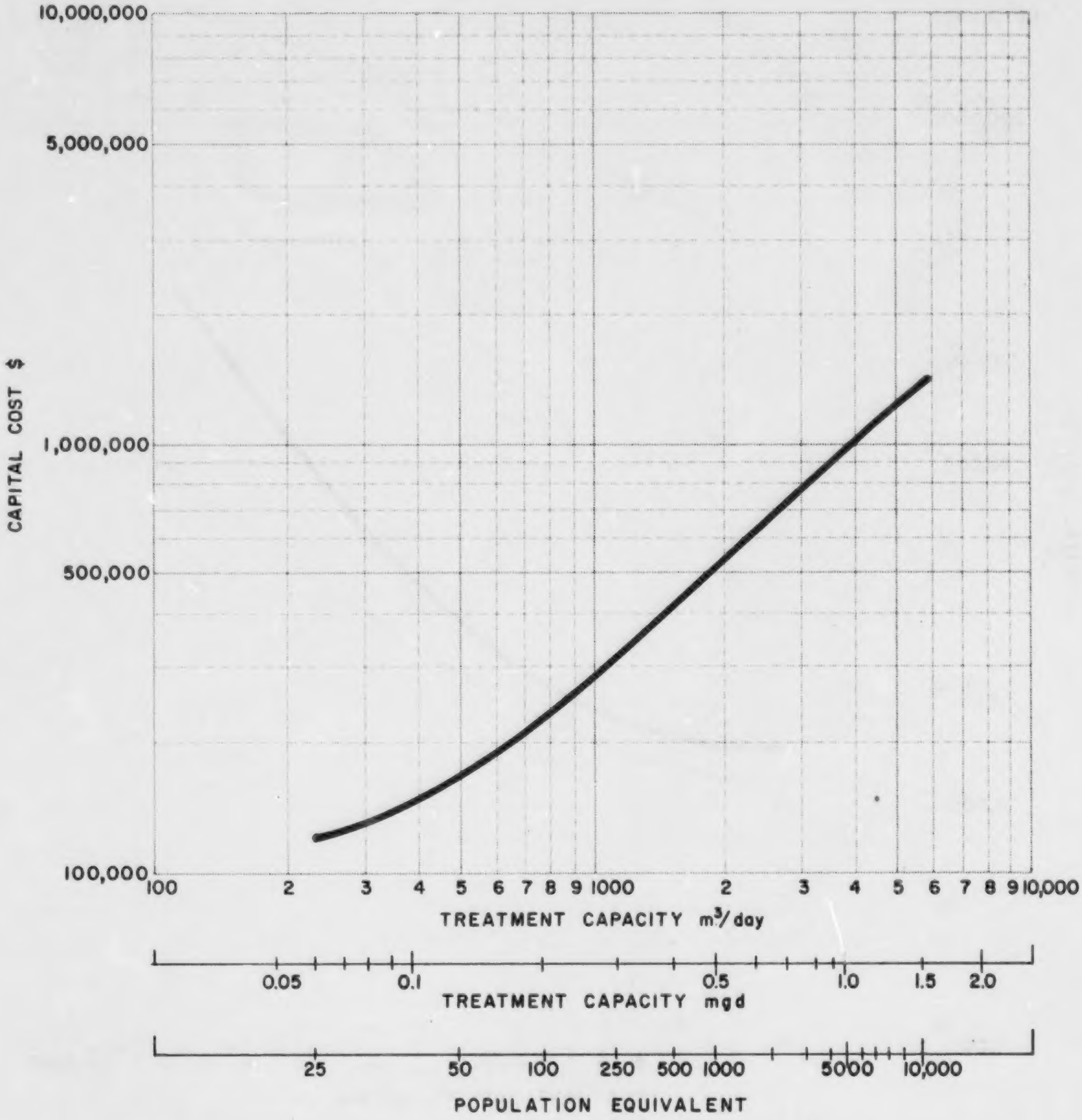


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- TWO-BED DEMINERALIZATION SYSTEM
- CATION & ANION EXCHANGE RESINS
- REGENERATION EQUIPMENT
- VALVES, PIPING & CONTROLS

DEMINERALIZATION
CAPITAL COST

FIGURE 16



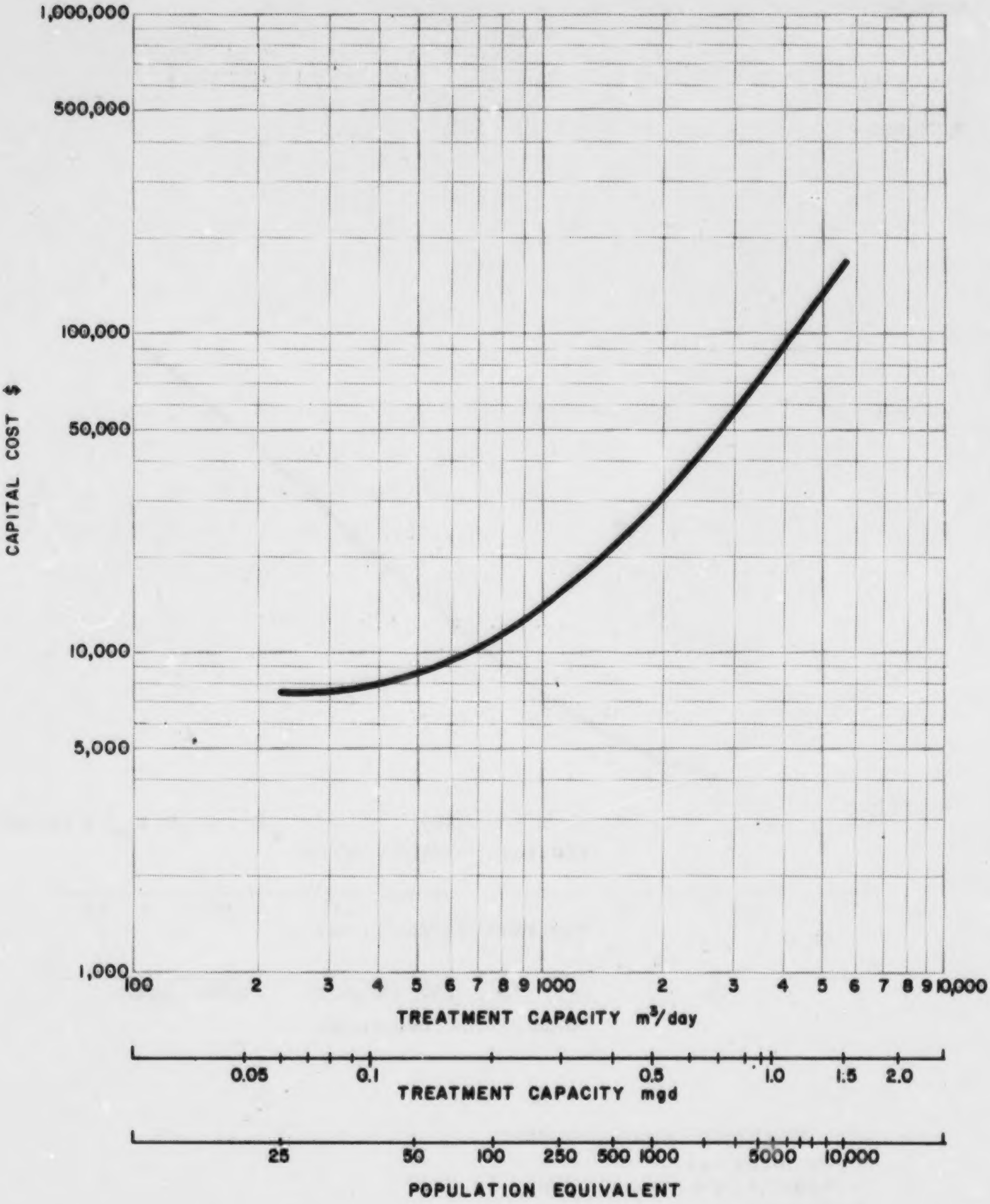
UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- REVERSE POLARITY ELECTRODIALYSIS SYSTEM

ELECTRODIALYSIS

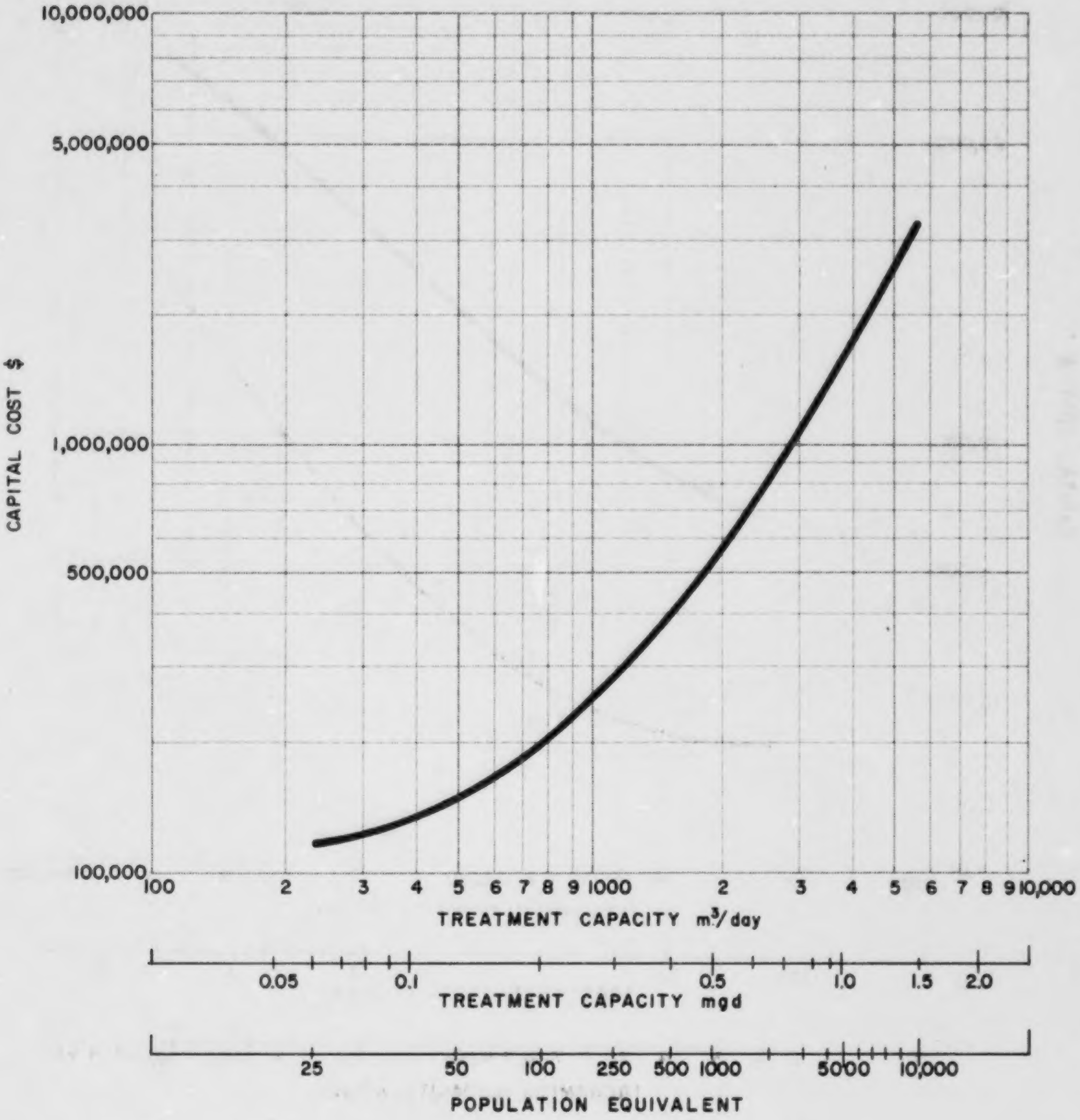
CAPITAL COST

FIGURE 17



ELECTRODIALYSIS ENCLOSURE
CAPITAL COST

FIGURE 18

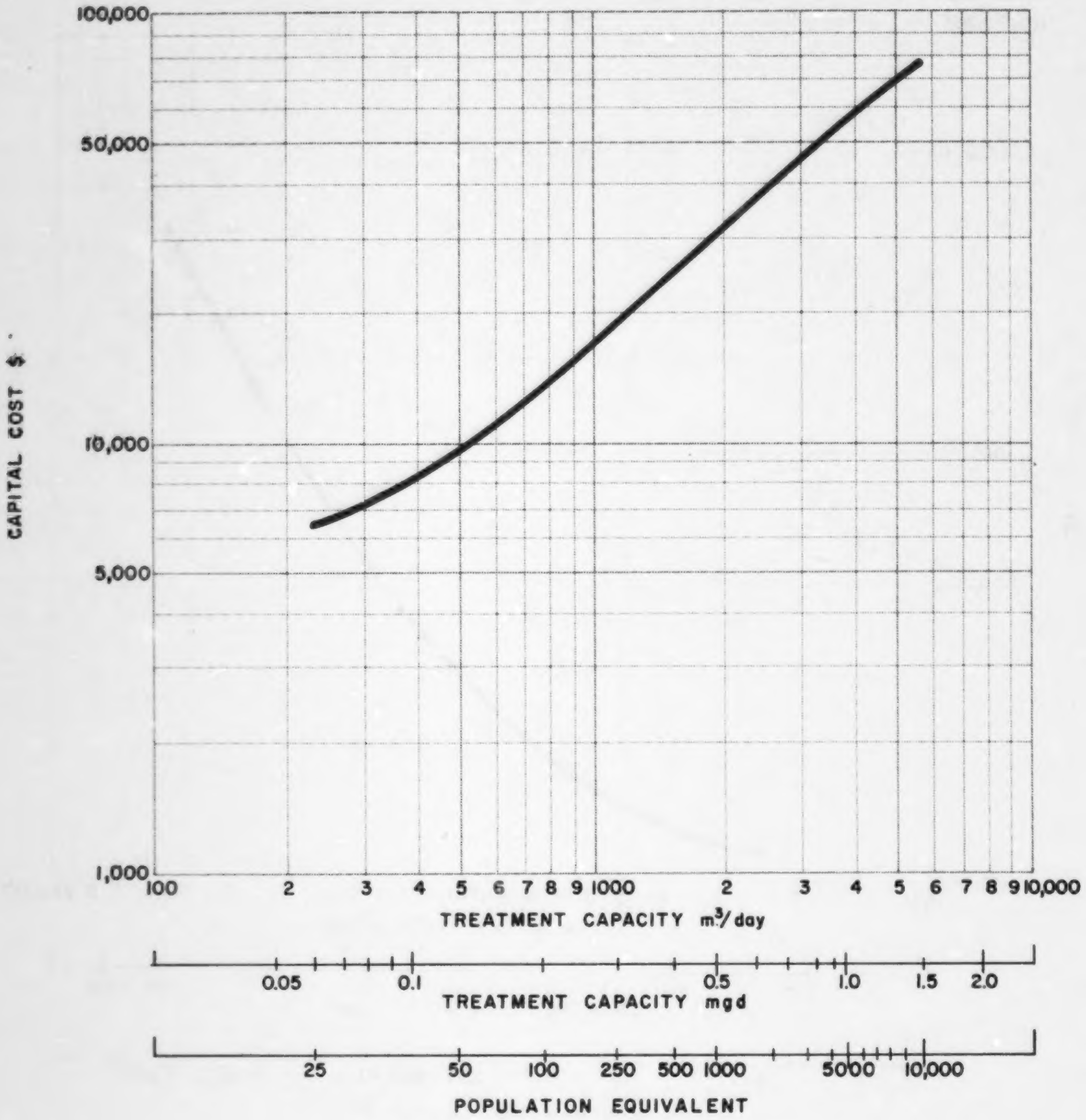


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- MEMBRANE TYPE REVERSE OSMOSIS SYSTEM

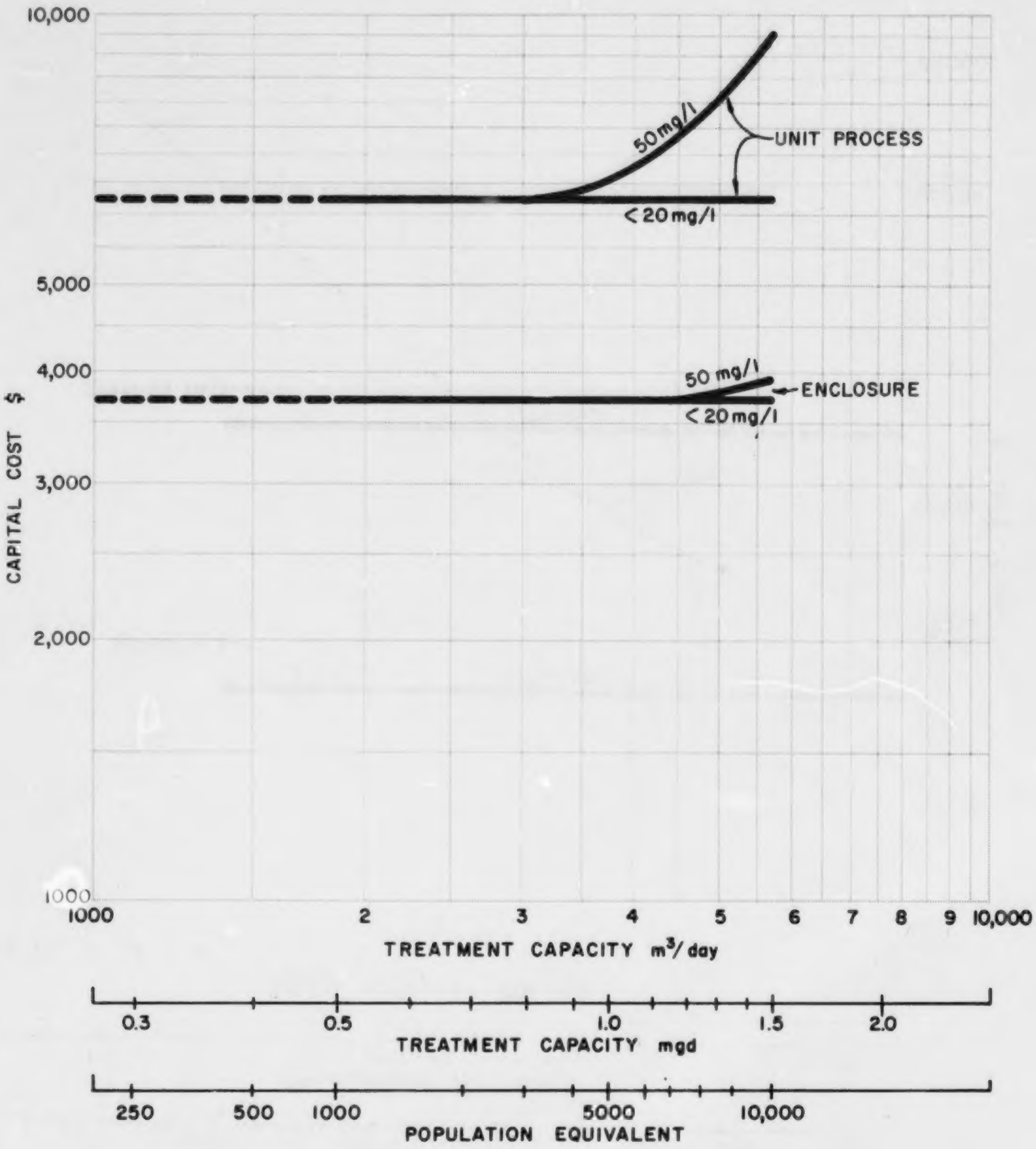
REVERSE OSMOSIS
CAPITAL COST

FIGURE 19



REVERSE OSMOSIS ENCLOSURE
CAPITAL COST

FIGURE 20

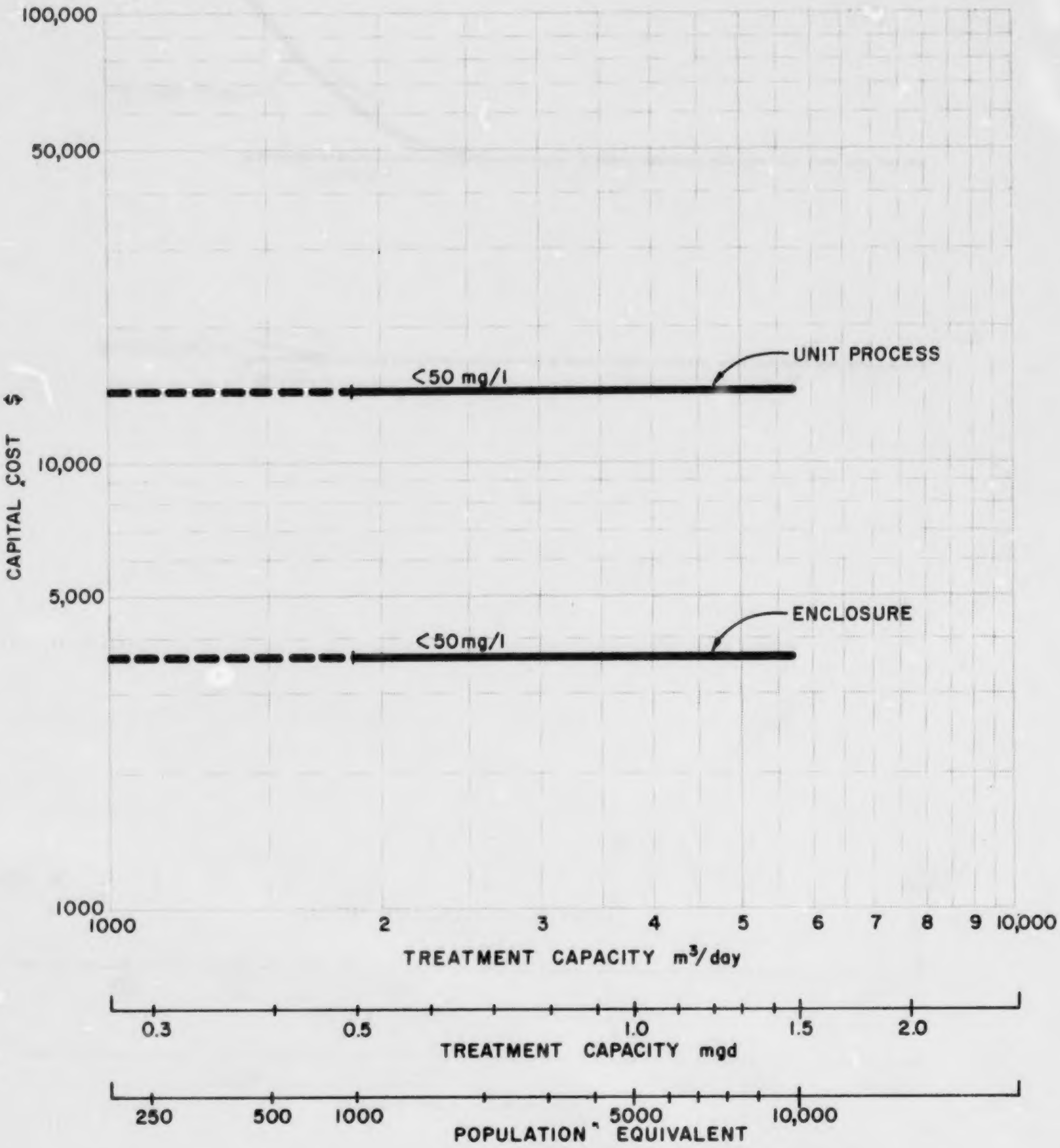


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

POWDERED ACTIVATED CARBON
CHEMICAL FEED
CAPITAL COST

FIGURE 21

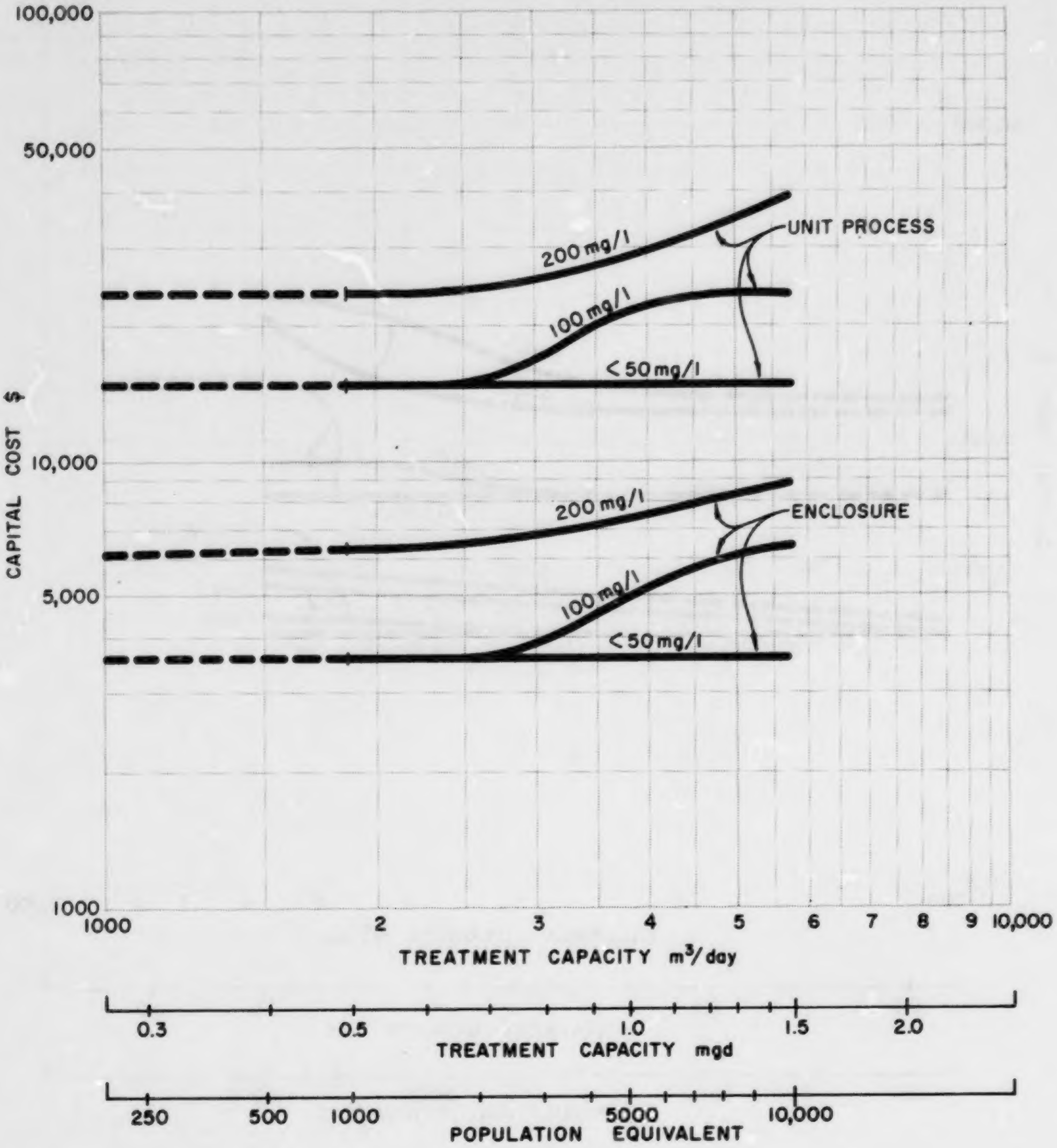


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

COAGULANT
CHEMICAL FEED
CAPITAL COST

FIGURE 22

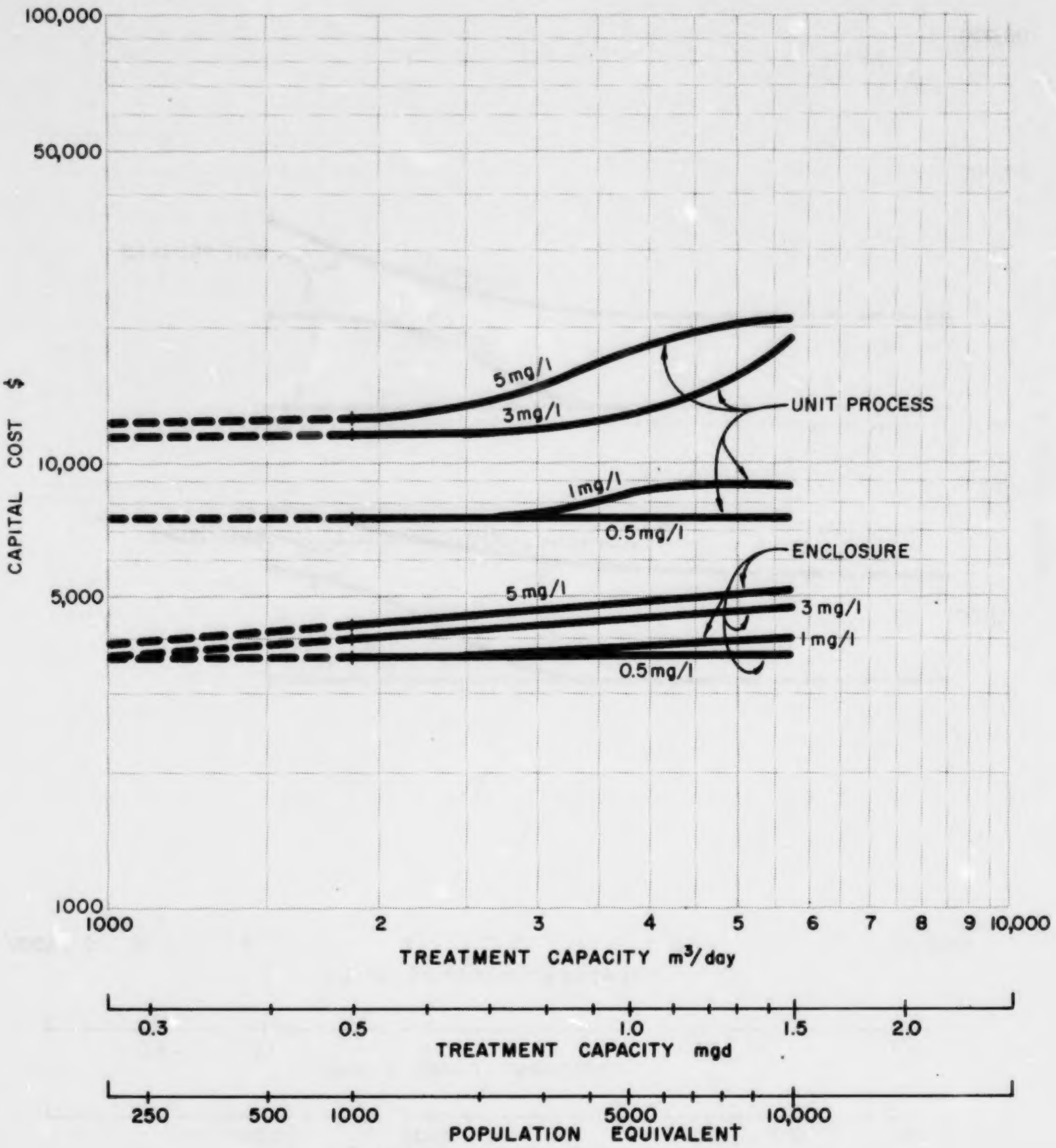


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

HYDRATED LIME
CHEMICAL FEED
CAPITAL COST

FIGURE 23

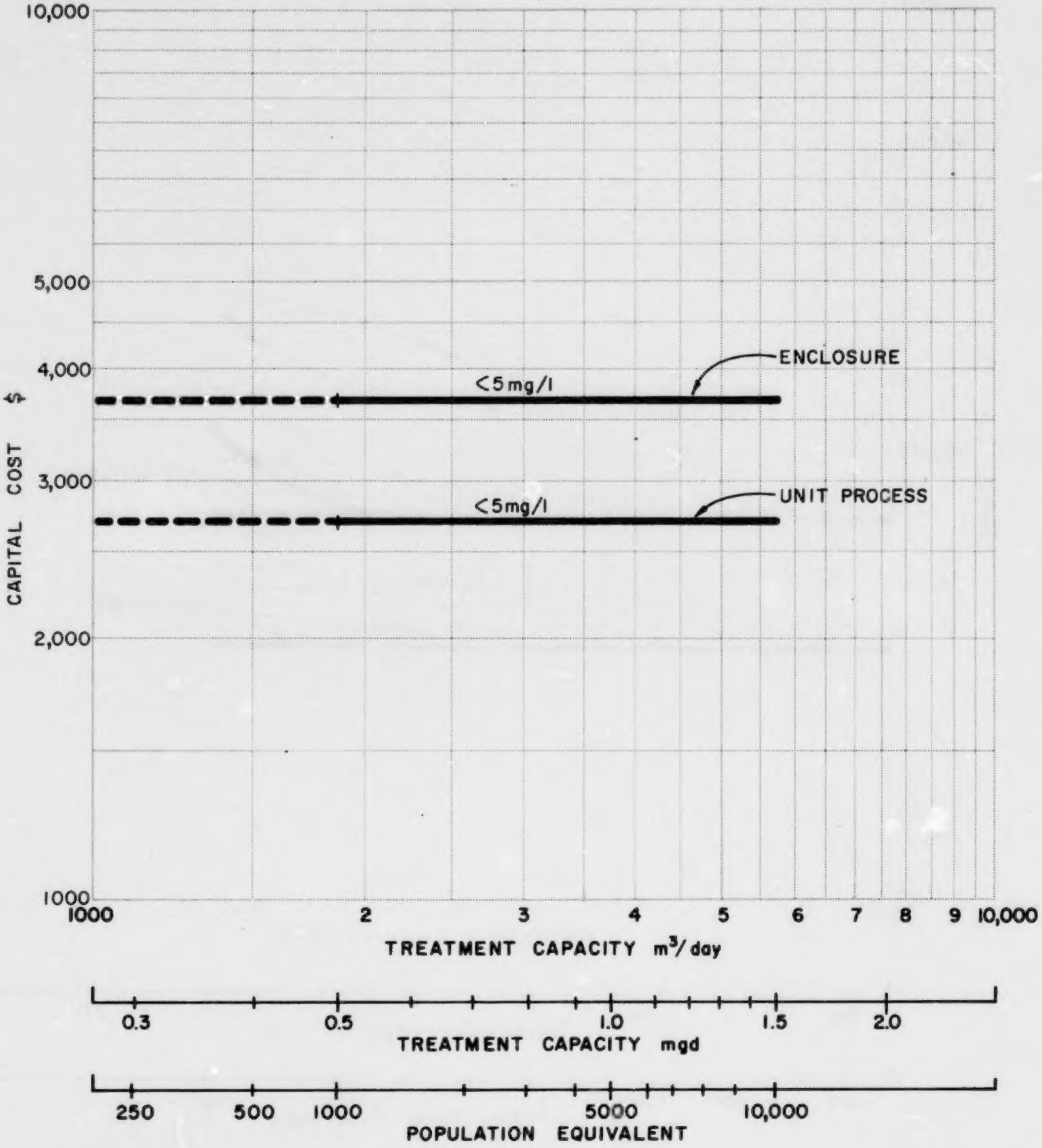


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

POLYMER
CHEMICAL FEED
CAPITAL COST

FIGURE 24

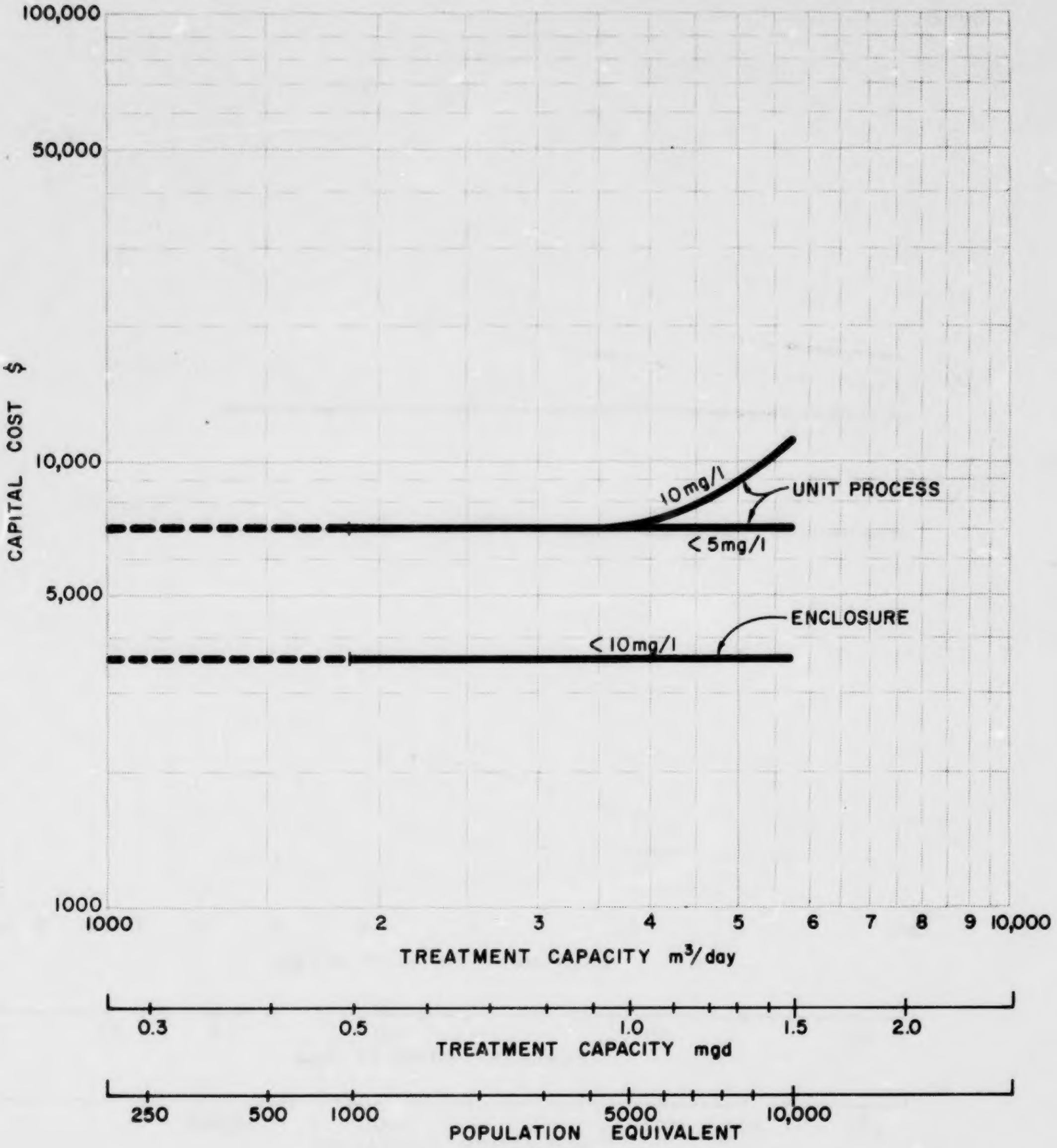


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

POLYPHOSPHATE
CHEMICAL FEED
CAPITAL COST

FIGURE 25

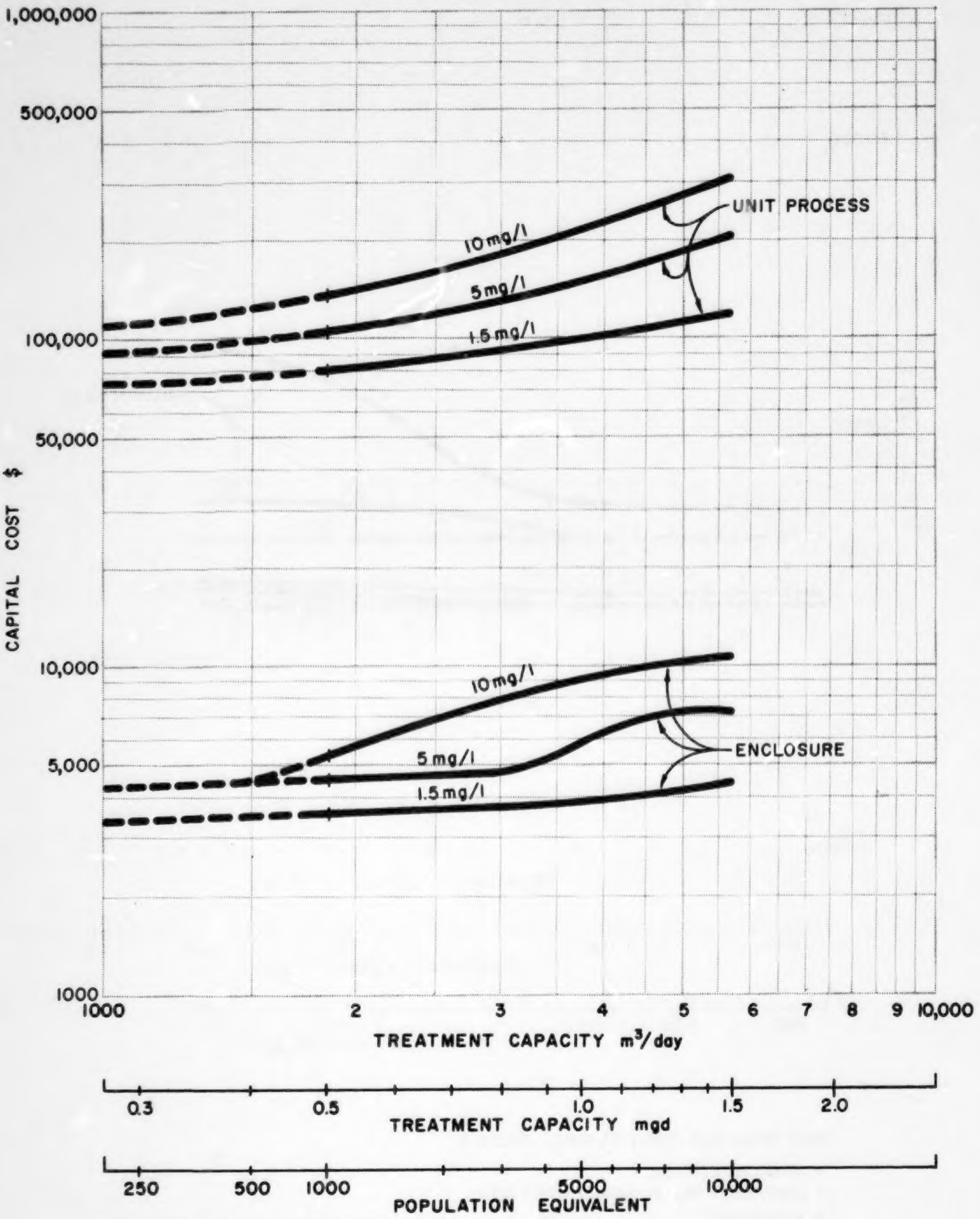


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

CHLORINE
CHEMICAL FEED
CAPITAL COST

FIGURE 26



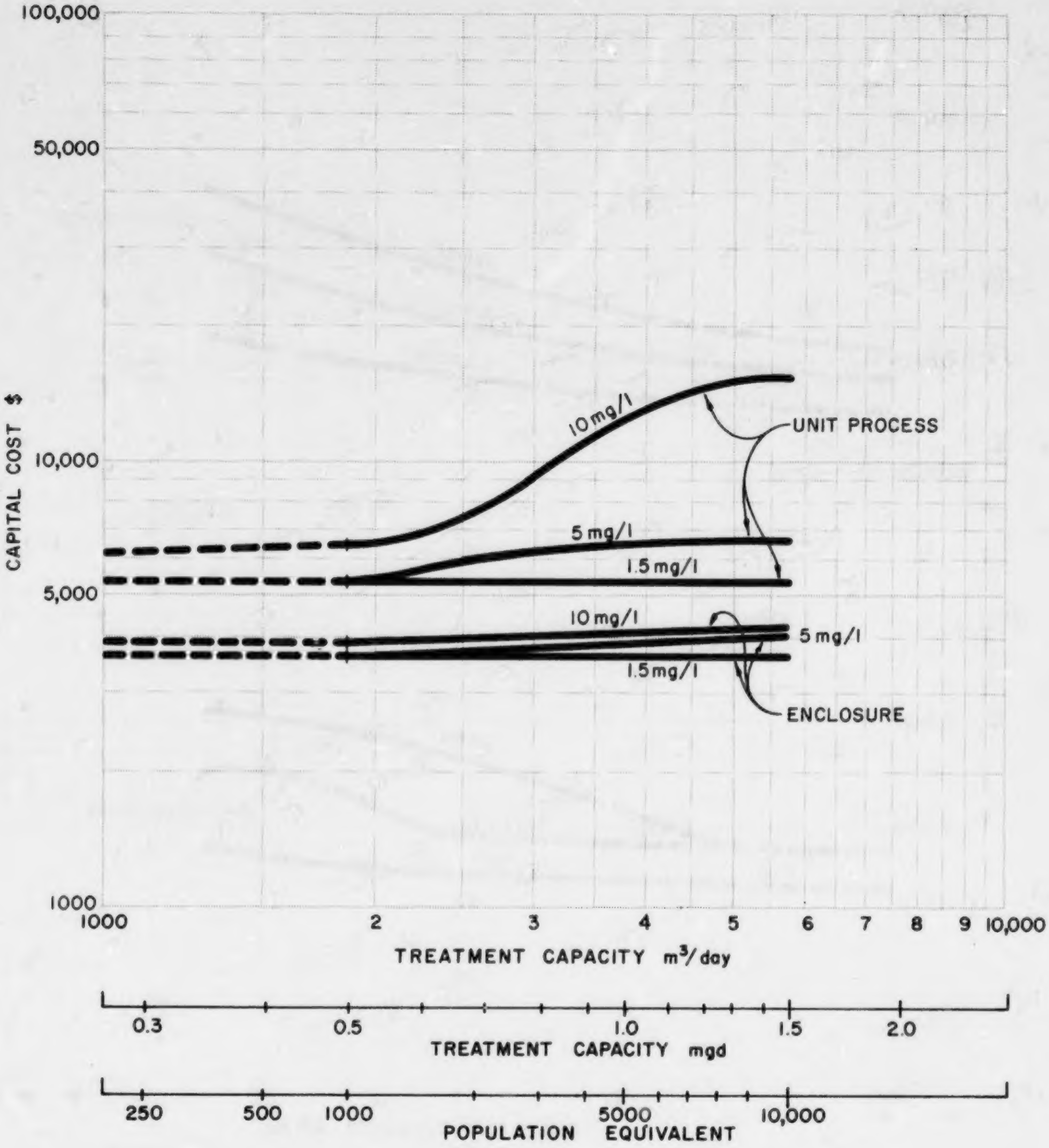
UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- AIR-FEED OZONE GENERATING SYSTEM
- CHEMICAL FEED EQUIPMENT

5 SHOTS

OZONE
ON-SITE GENERATION
CAPITAL COST

FIGURE 27

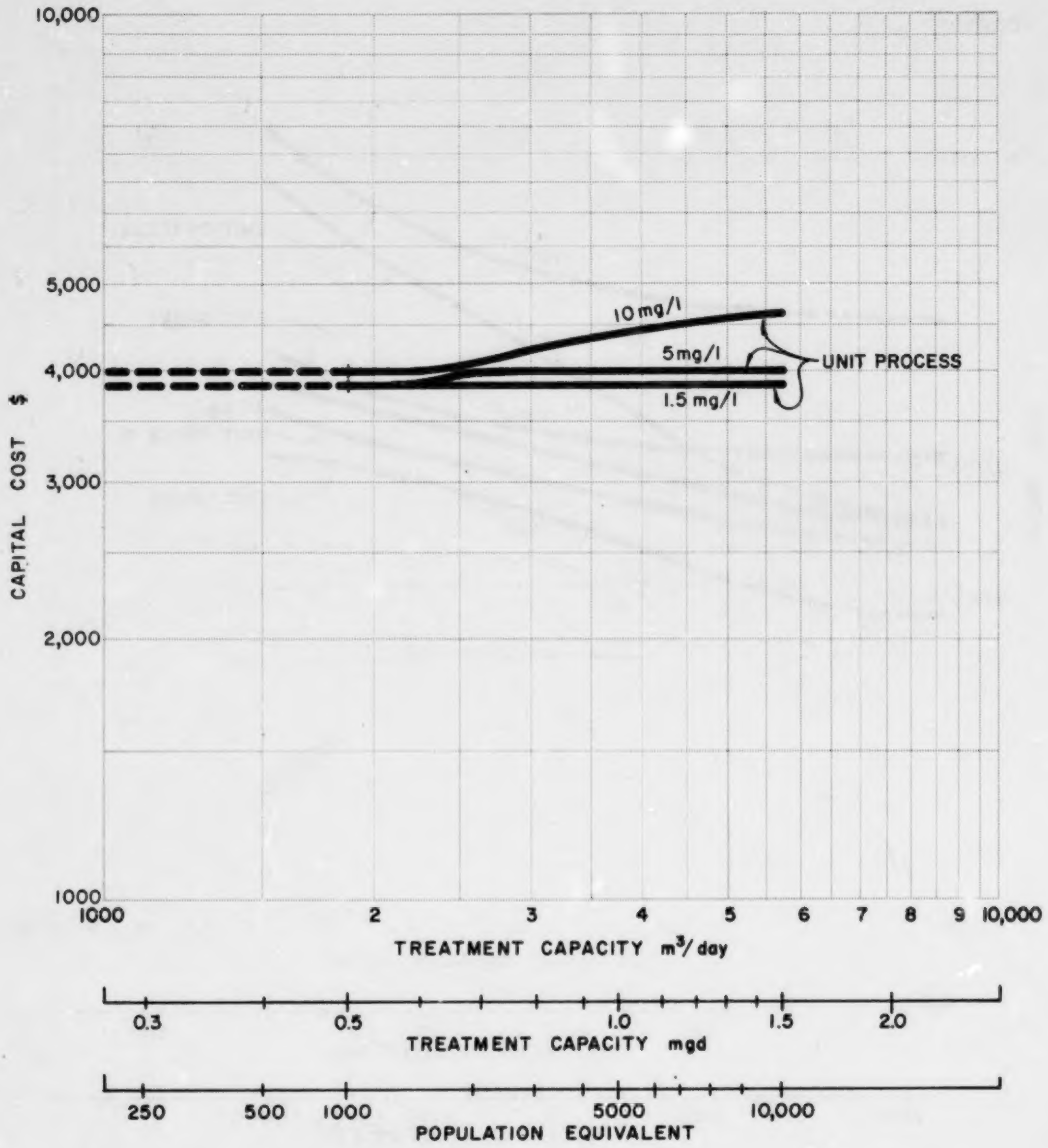


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

CALCIUM HYPOCHLORITE
CHEMICAL FEED
CAPITAL COST

FIGURE 28



UNIT PROCESS COST CURVES INCLUDE:

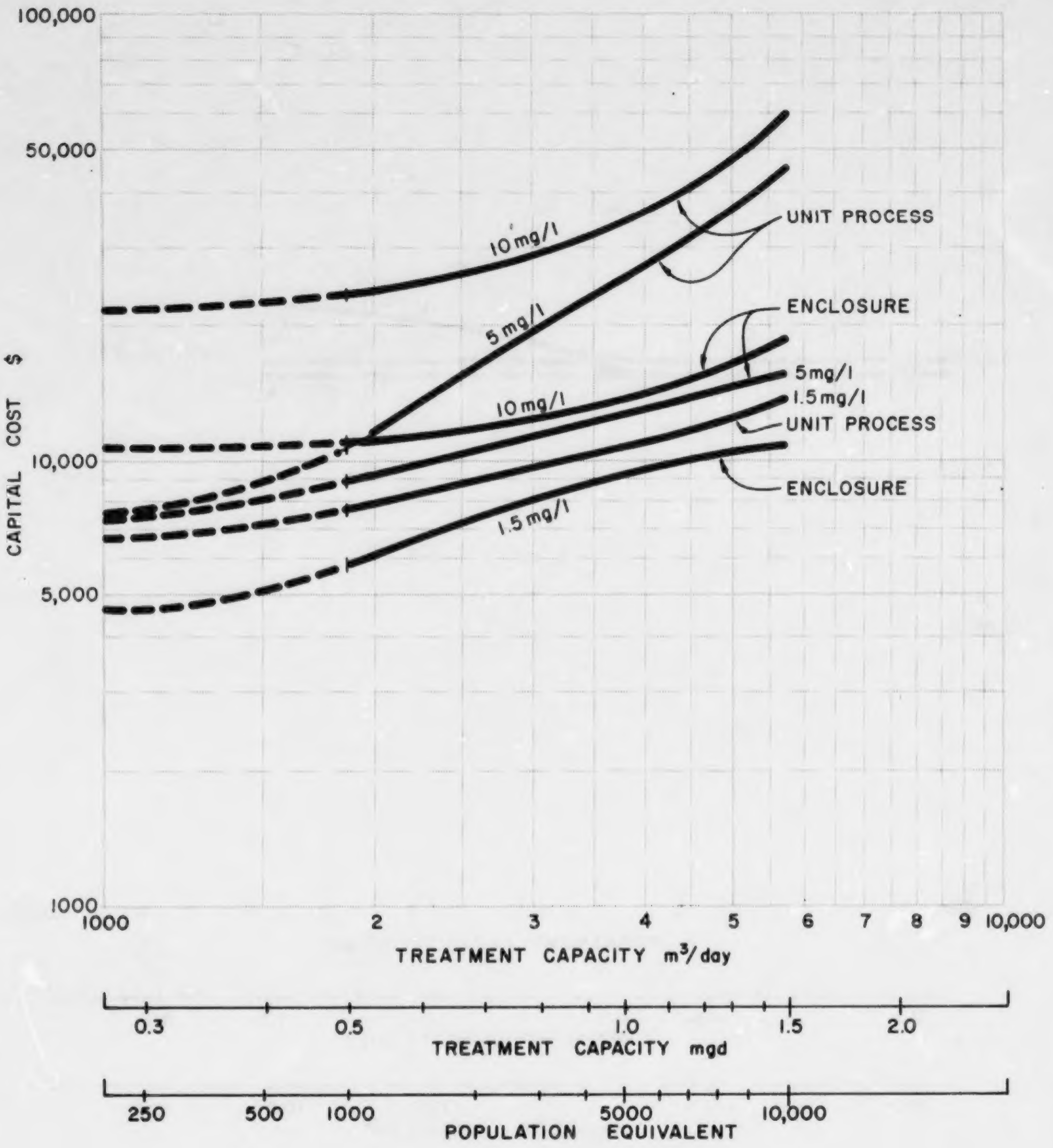
- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- CHEMICAL FEED EQUIPMENT

NOTE:

ENCLOSURE CAPITAL COST FOR ALL SIZES IS $3700.

SODIUM HYPOCHLORITE
CHEMICAL FEED
CAPITAL COST

FIGURE 29

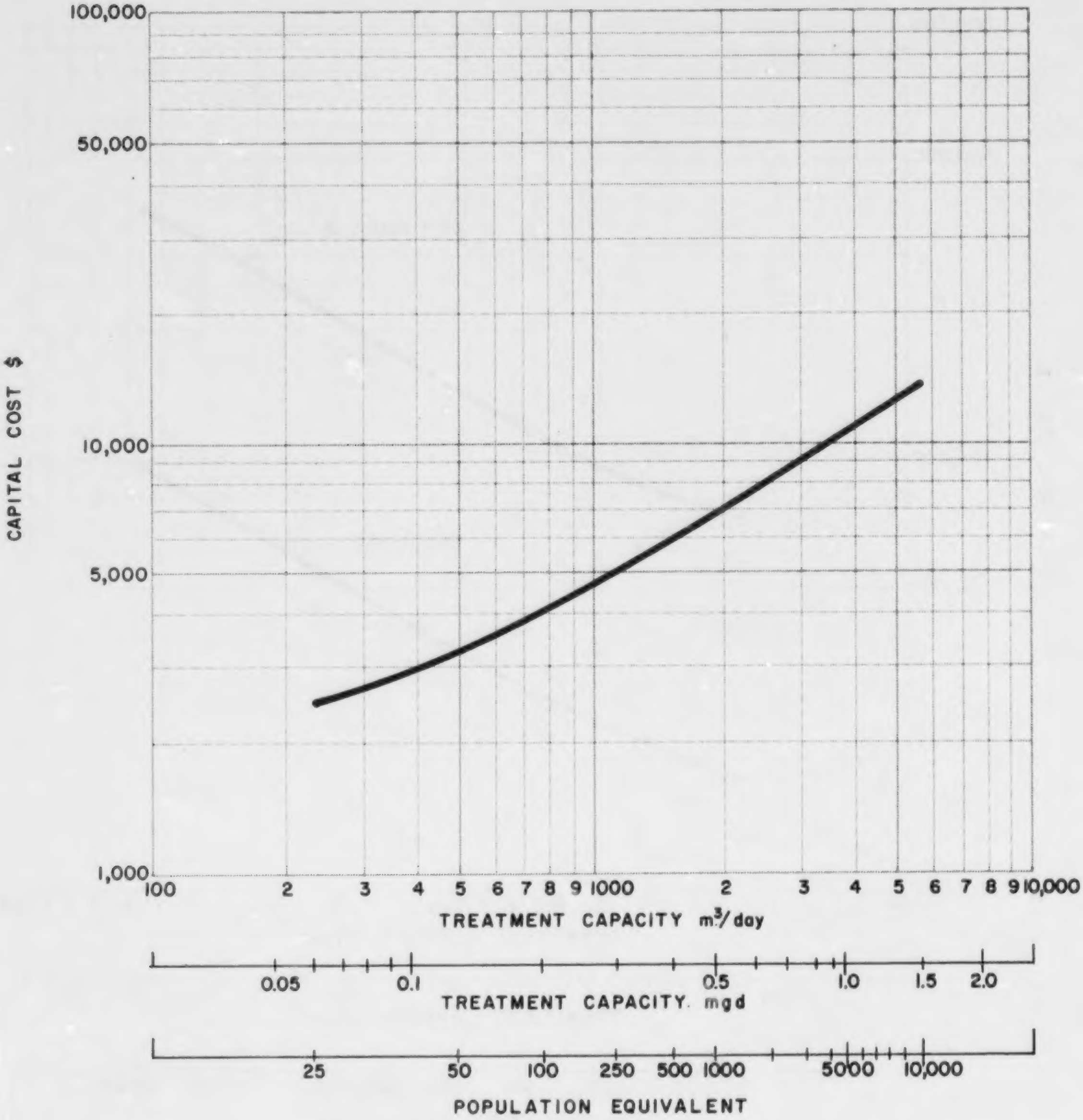


UNIT PROCESS COST CURVES INCLUDE:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- SITEWORK
- ELECTRICAL
- SALT FEED SODIUM HYPOCHLORITE GENERATING SYSTEM
- CHEMICAL FEED EQUIPMENT

SODIUM HYPOCHLORITE
ON-SITE GENERATION
CAPITAL COST

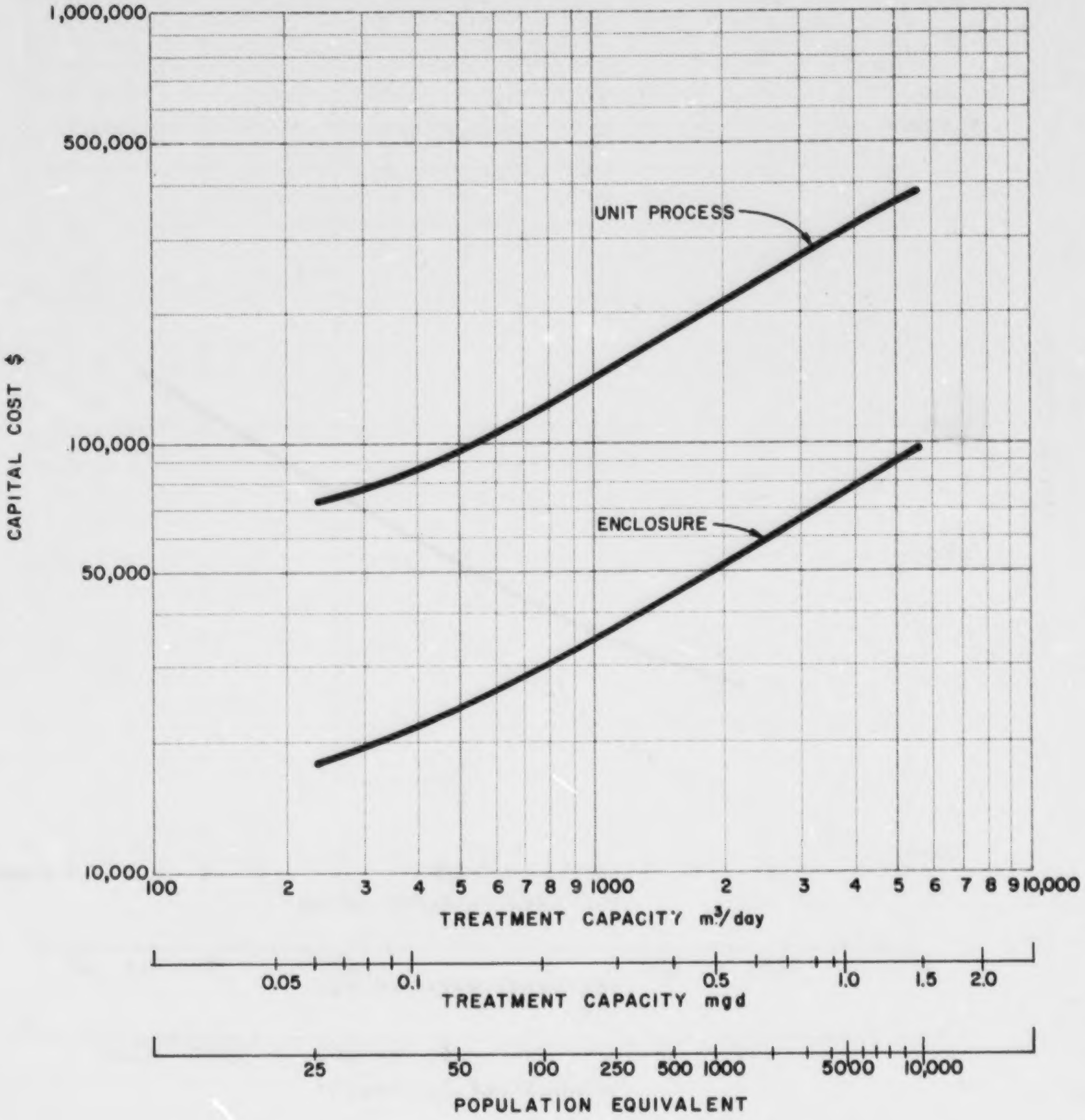
FIGURE 30



UNIT PROCESS COST CURVE INCLUDES:
- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- EXCAVATION
- FENCING

WASTE SOLIDS DISPOSAL
LAGOON
CAPITAL COST

FIGURE 31

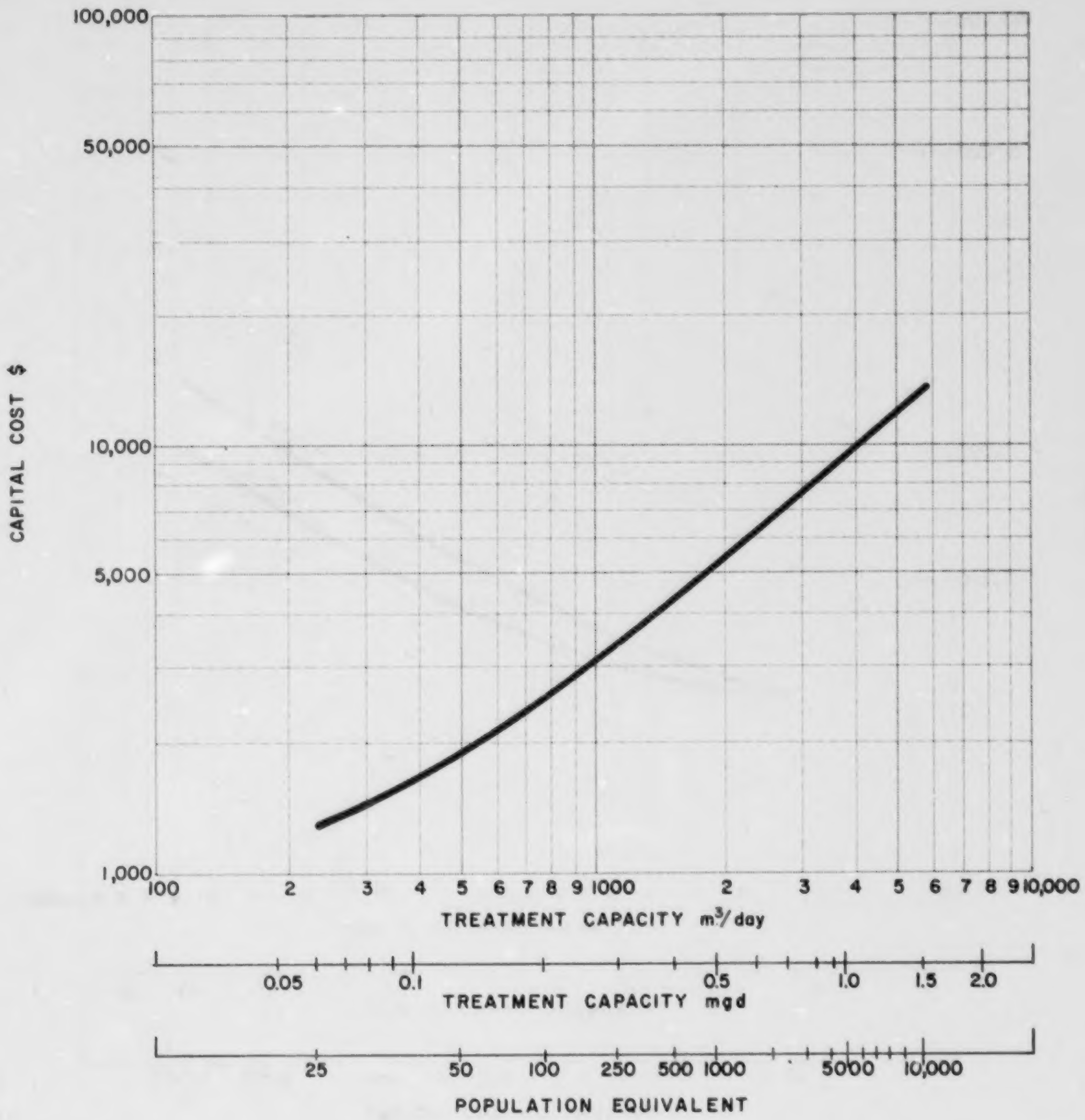


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- INSTALLED PACKAGE TREATMENT SYSTEM

PACKAGE PLANT
CAPITAL COST

FIGURE 32

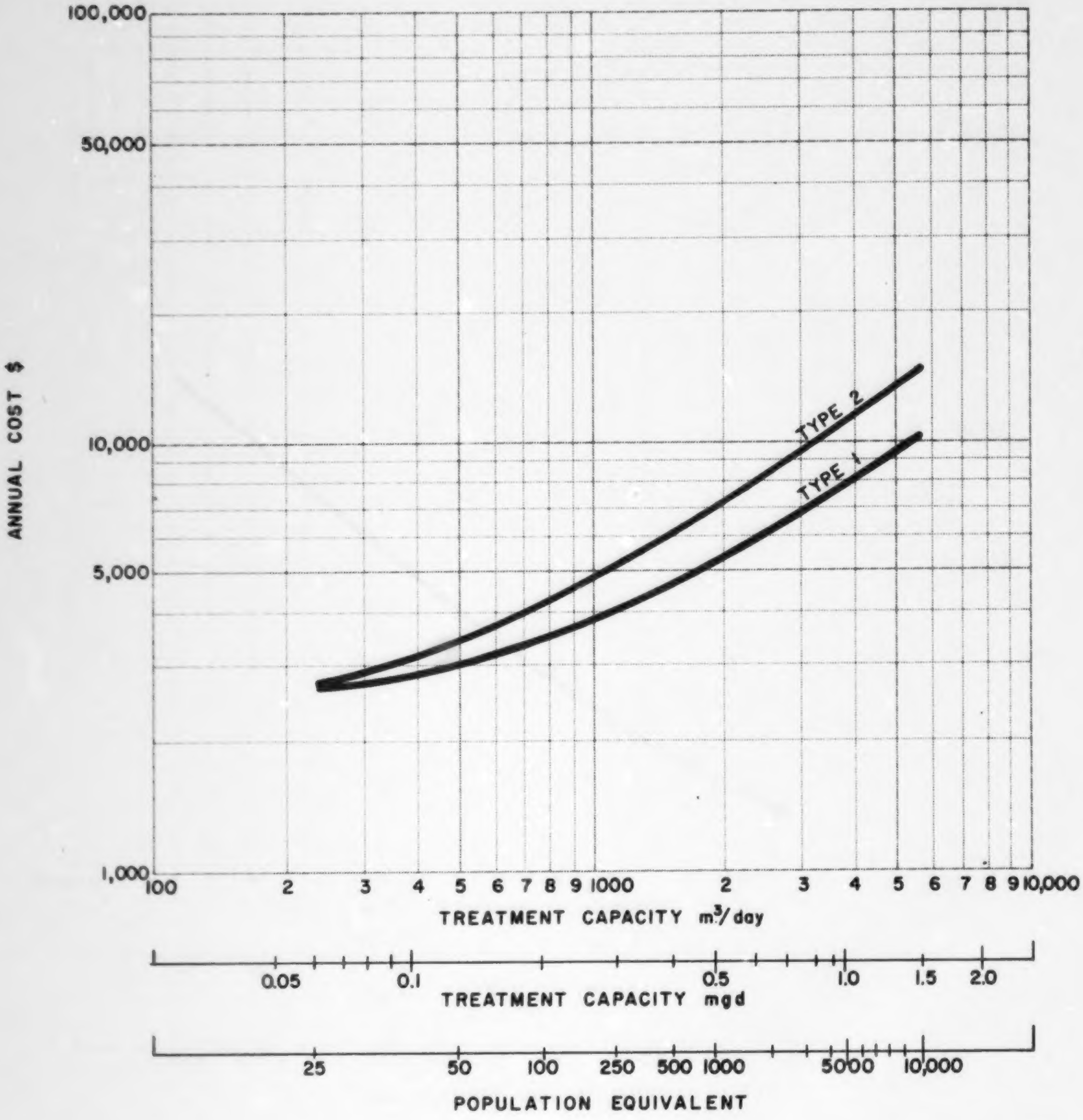


UNIT PROCESS COST CURVE INCLUDES:

- CONTINGENCIES
- ENGINEERING & ADMINISTRATION
- TUBE SETTLERS
- SUPPORT MATERIALS

TUBE SETTLERS
CAPITAL COST

FIGURE 33



COST CURVES INCLUDE:

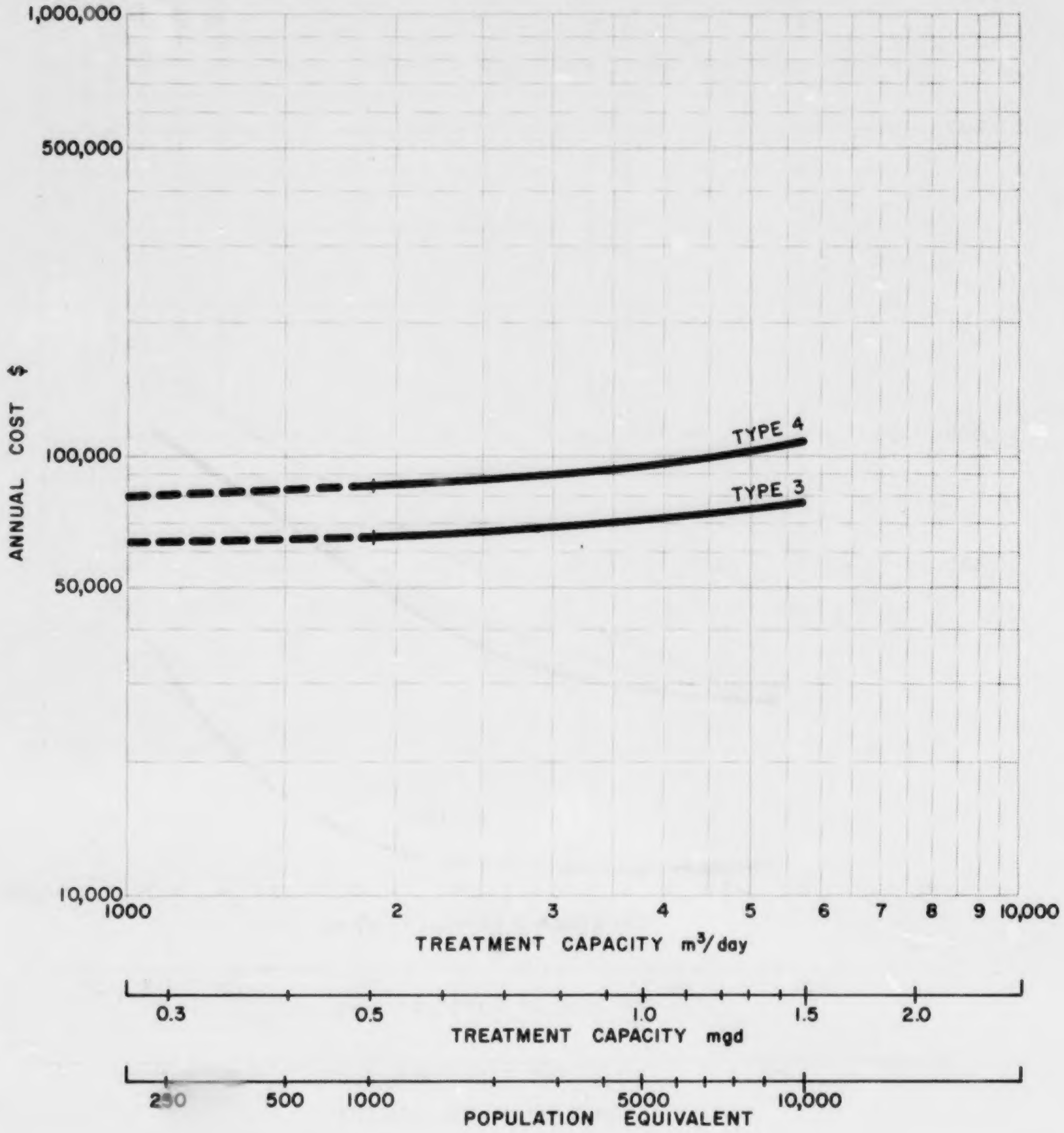
- WAGES
- FRINGE BENEFITS

NOTE:

REFER TO SECTION VI B FOR DEFINITION OF TYPE I & 2

LABOR-PLANT TYPE I & 2
OPERATION AND MAINTENANCE COST

FIGURE 34



COST CURVES INCLUDE:

- WAGES
- FRINGE BENEFITS

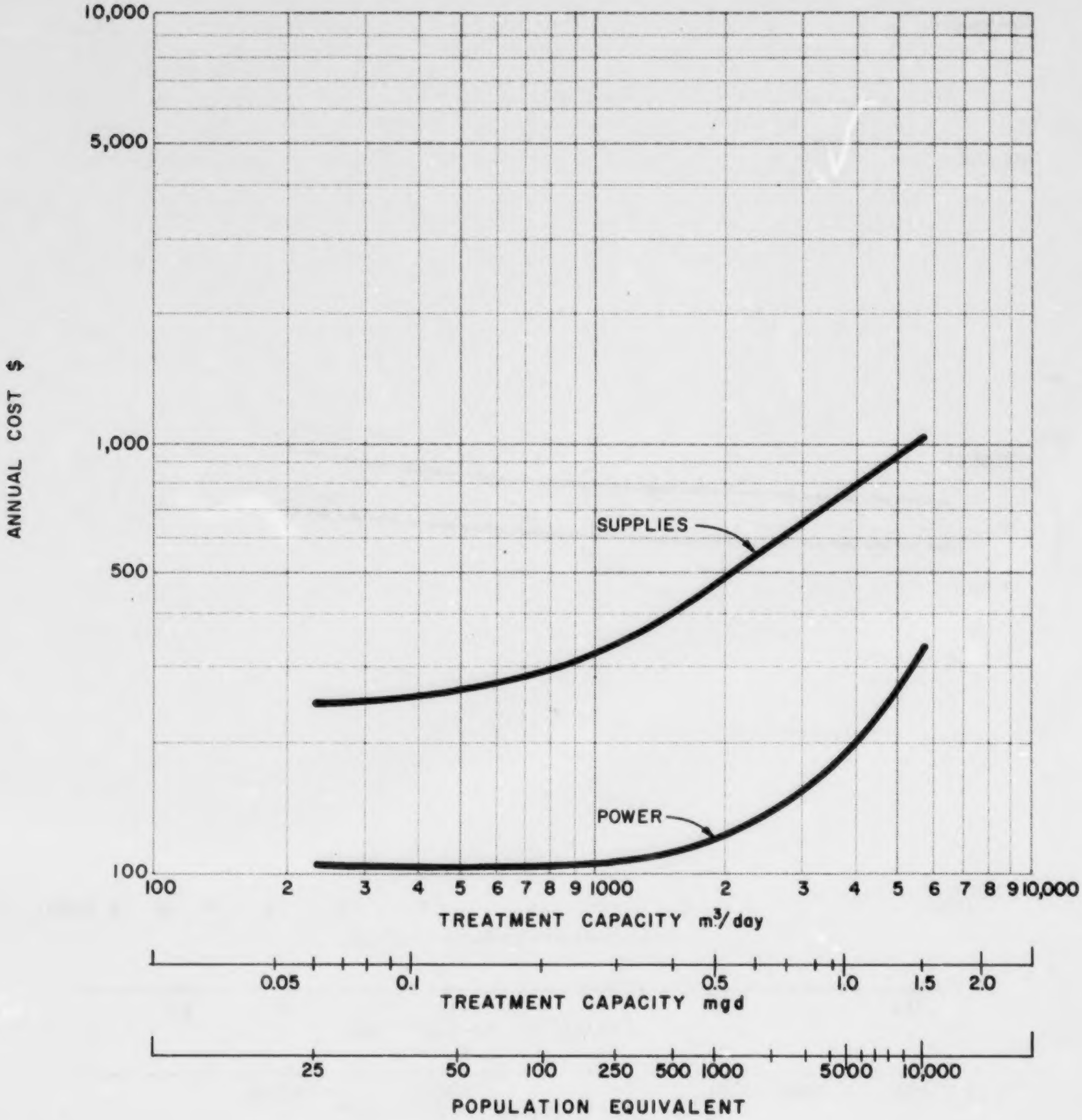
NOTE:

REFER TO SECTION VI B FOR DEFINITION OF TYPE 3 & 4.

LABOR-PLANT TYPE 3 & 4

OPERATION AND MAINTENANCE COST

FIGURE 35

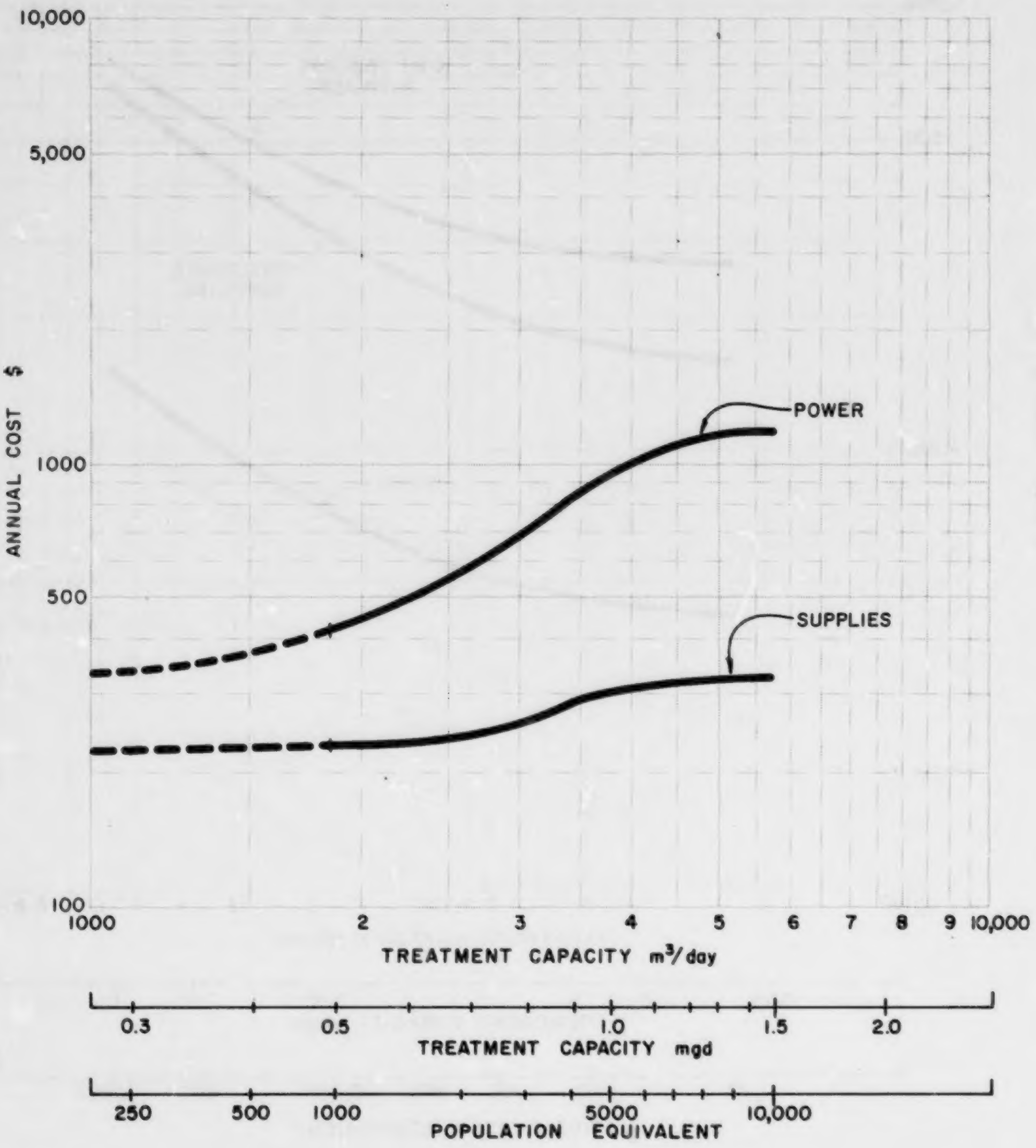


NOTE:

EXCLUDES LABOR. SEE
PAGE VI -16.

MECHANICAL AERATION
OPERATION AND MAINTENANCE COST

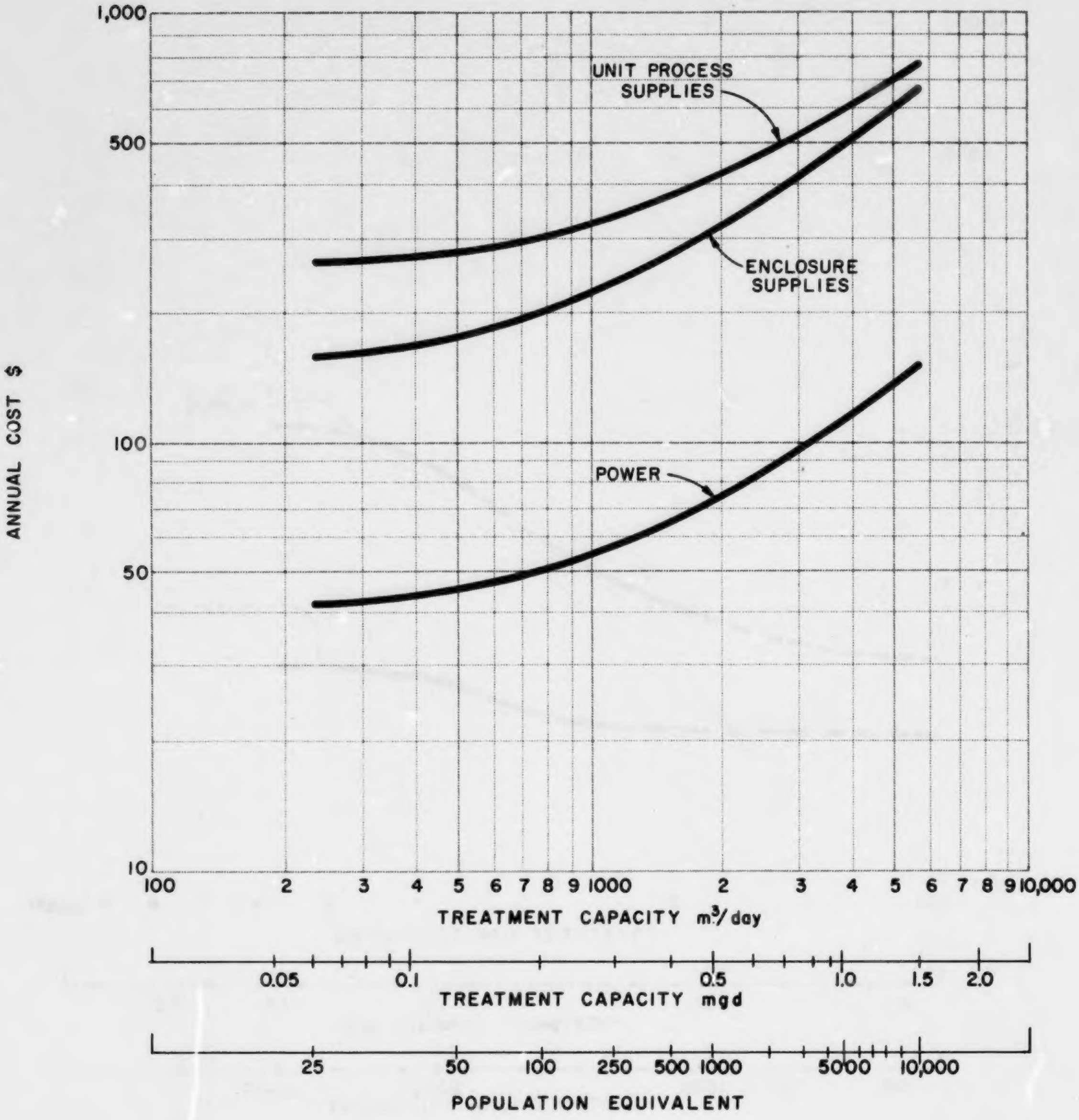
FIGURE 36



NOTE:
EXCLUDES LABOR. SEE
PAGE VI - 16.

DIFFUSED AERATION
OPERATION AND MAINTENANCE COST

FIGURE 37

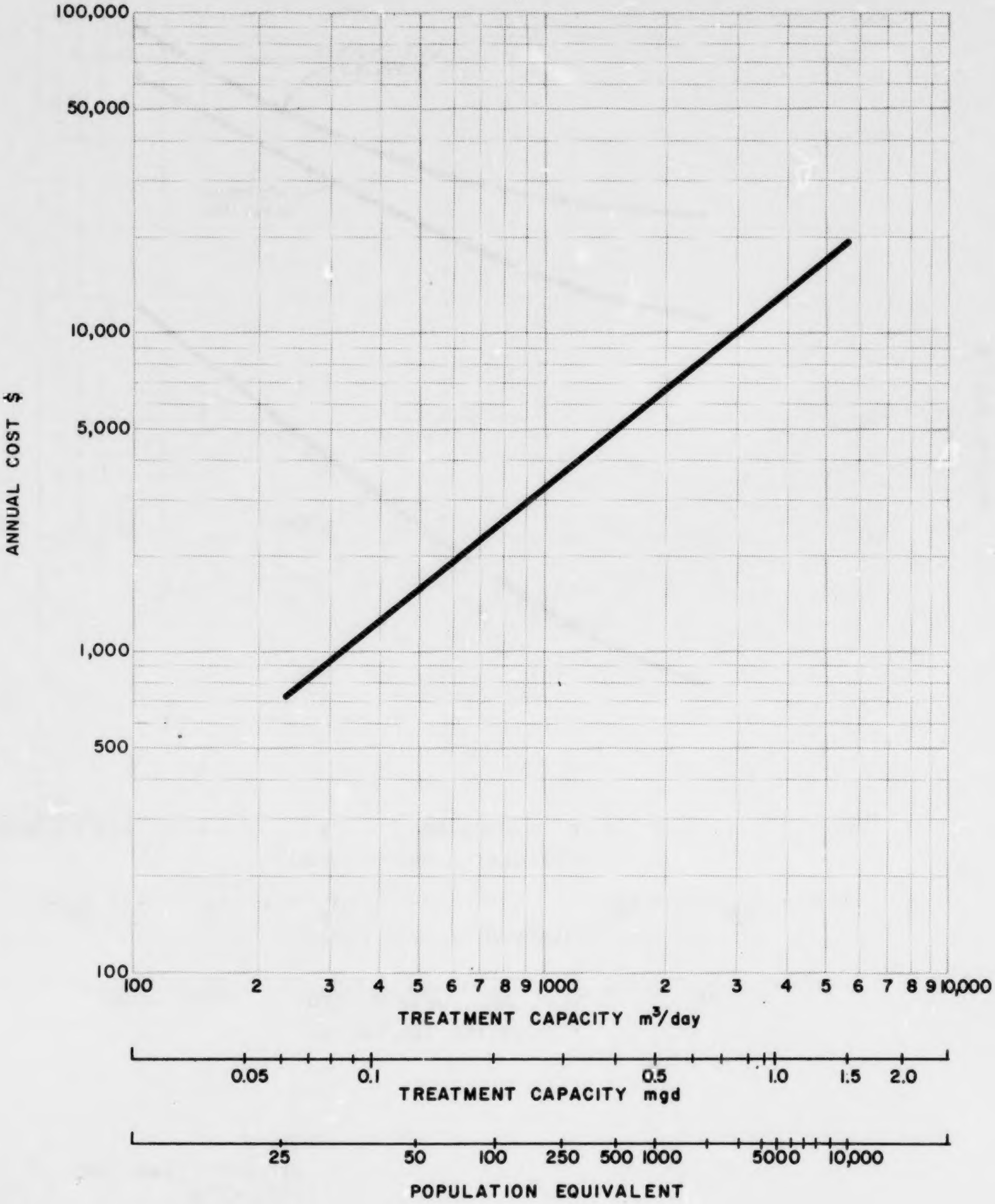


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

ACTIVATED CARBON BED
OPERATION AND MAINTENANCE COST

FIGURE 38

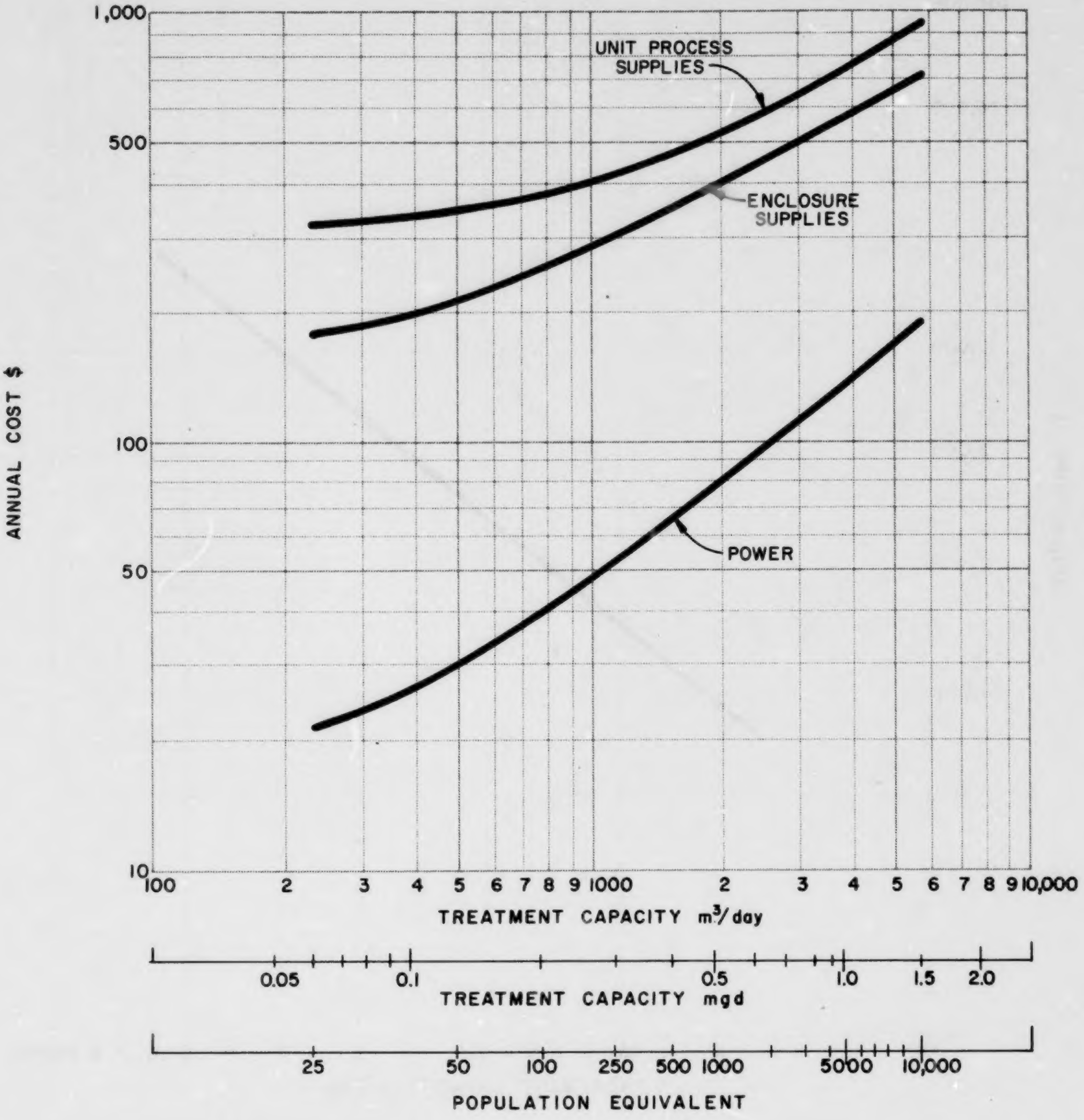


COST CURVE INCLUDES:

- CUSTOM REGENERATION
- FREIGHT

ACTIVATED CARBON BED
MEDIA REPLACEMENT COST

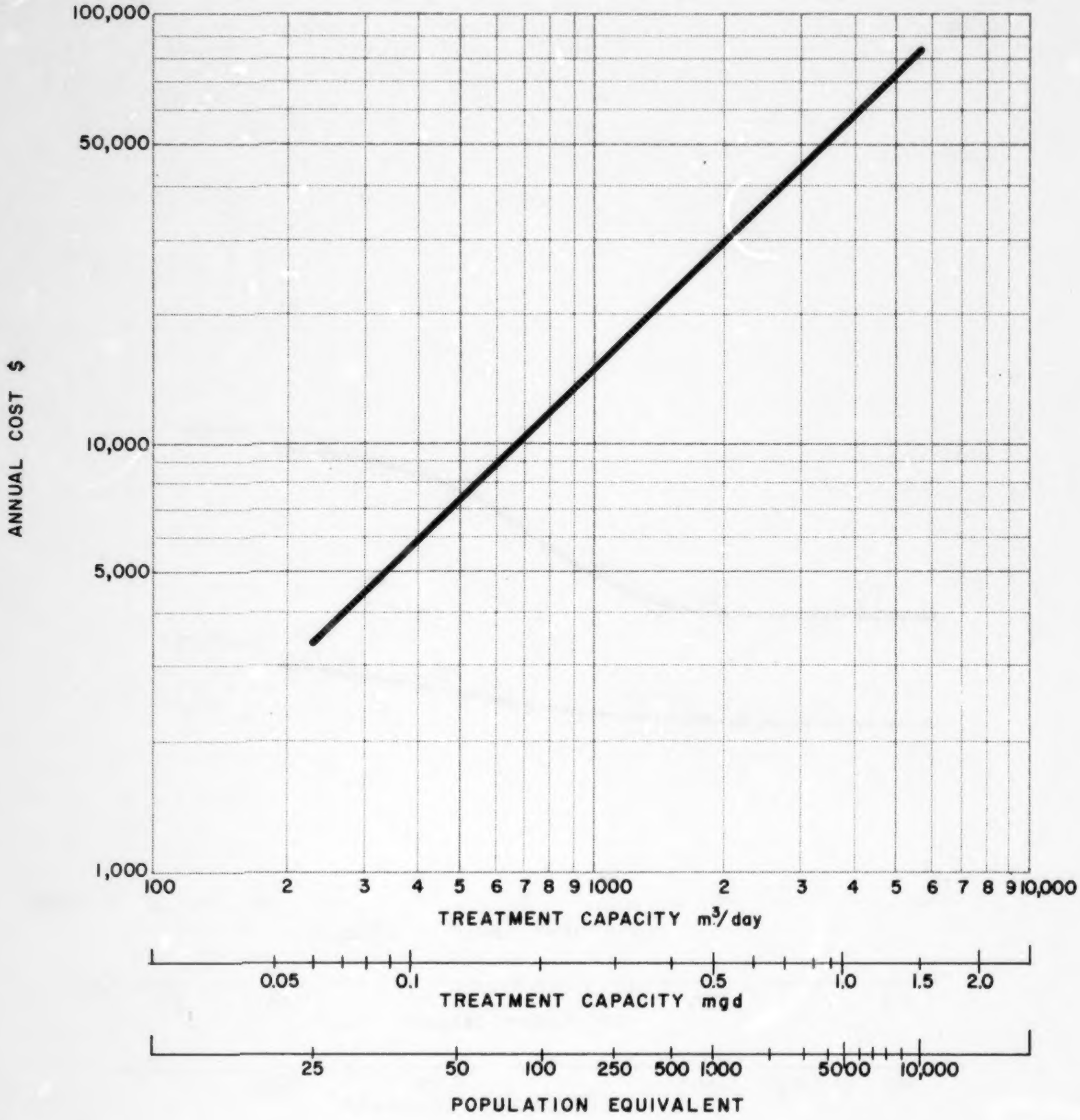
FIGURE 39



NOTE:
EXCLUDES LABOR. SEE PAGE VI-16.

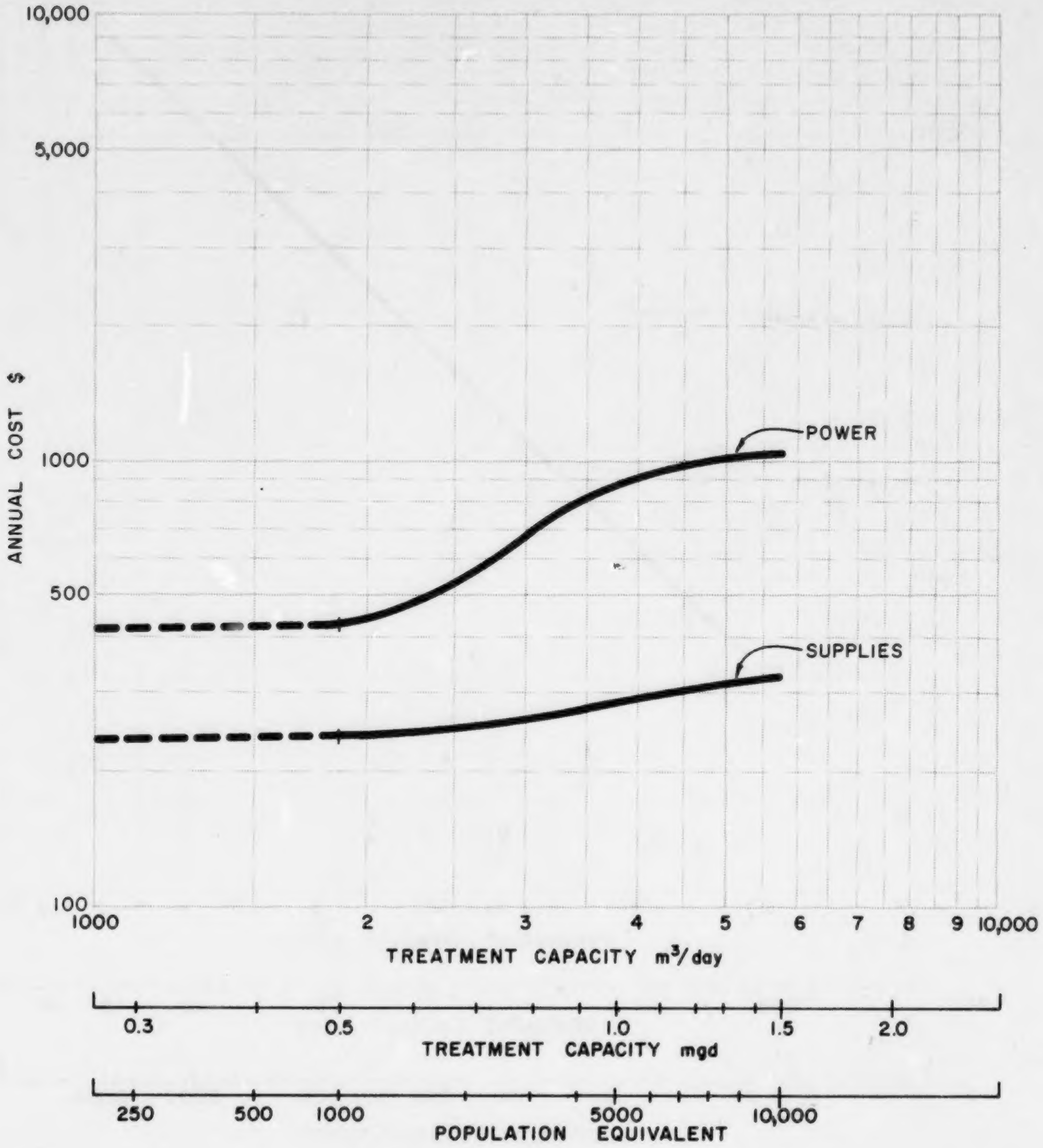
ACTIVATED ALUMINA COLUMN
OPERATION AND MAINTENANCE COST

FIGURE 40



ACTIVATED ALUMINA COLUMN
REGENERATIVE CHEMICAL COST

FIGURE 41



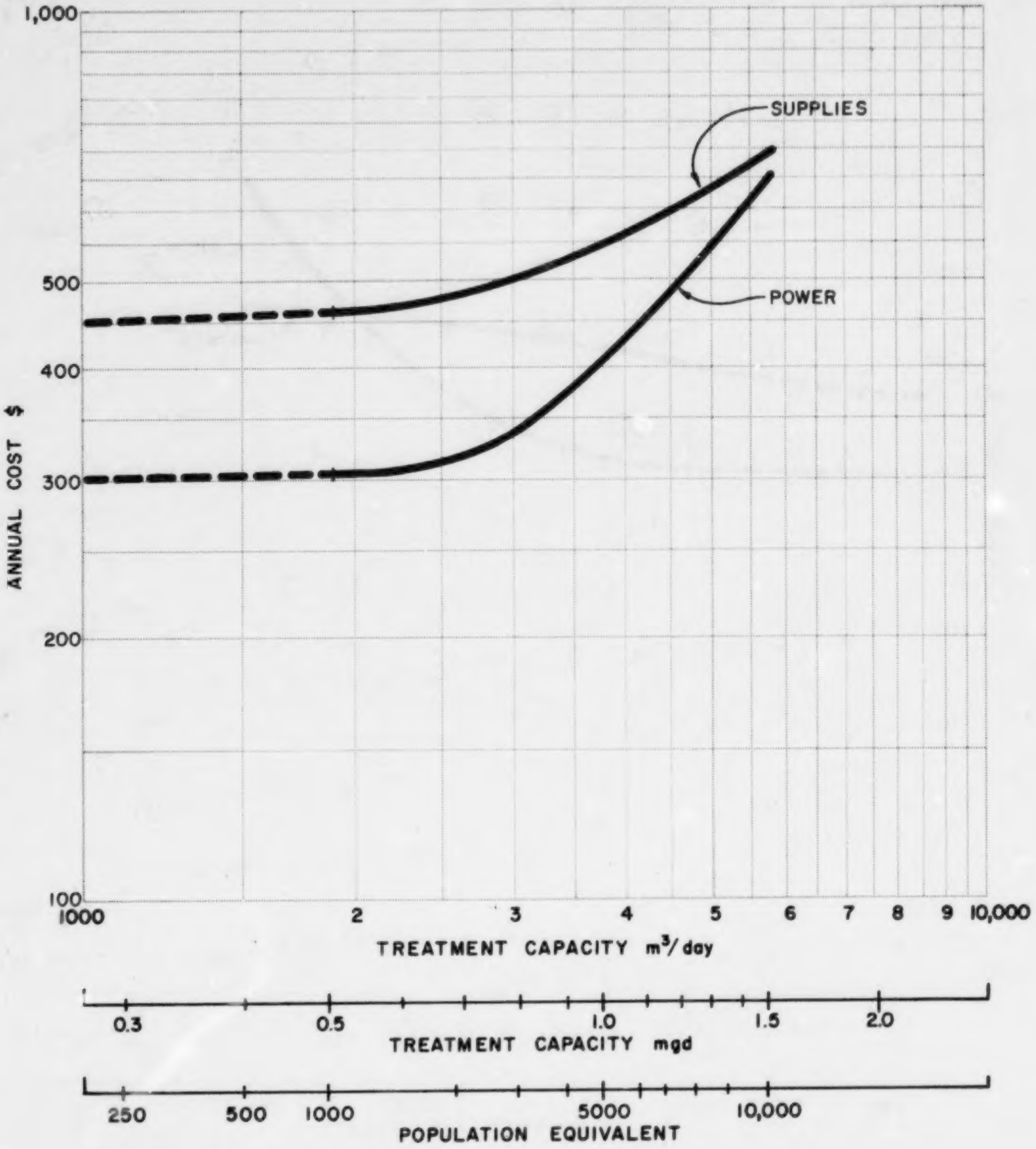
NOTE:

EXCLUDES LABOR. SEE PAGE VII-16.

RAPID MIX

OPERATION AND MAINTENANCE COST

FIGURE 42

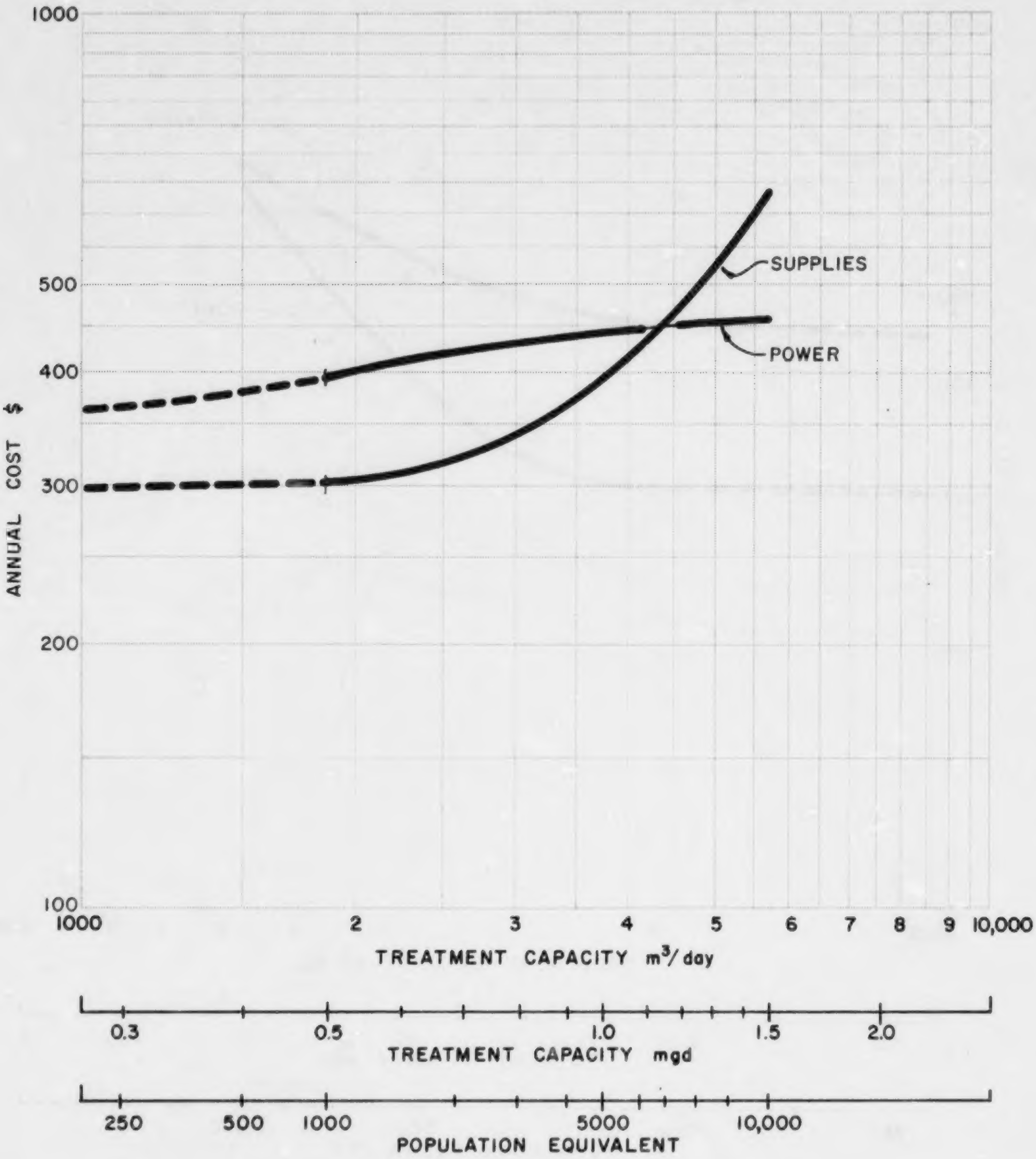


NOTE :
EXCLUDES LABOR. SEE
PAGE VI - 16.

FLOCCULATION

OPERATION AND MAINTENANCE COST

FIGURE 43



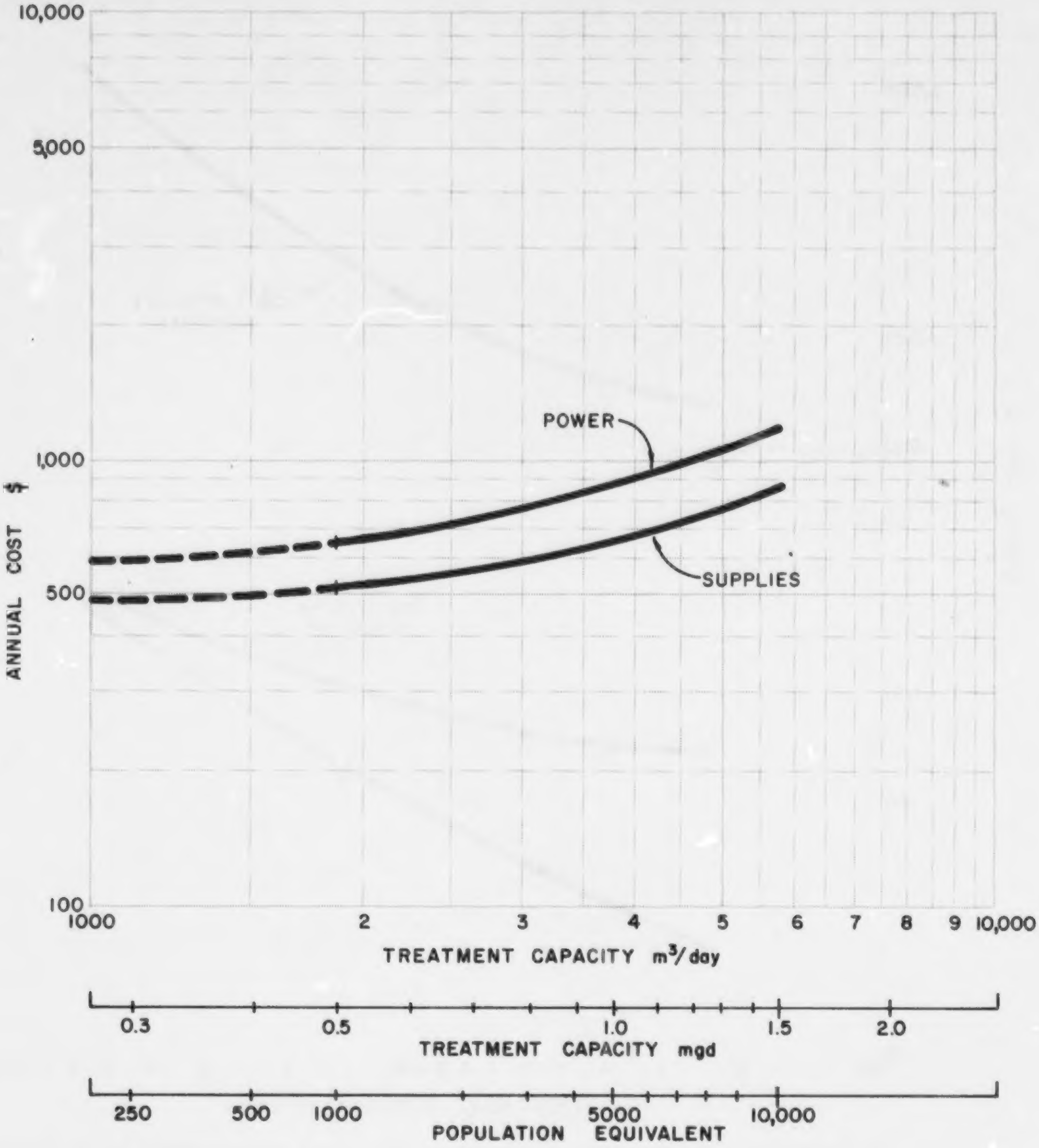
NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

SEDIMENTATION.

OPERATION AND MAINTENANCE COST

FIGURE 44

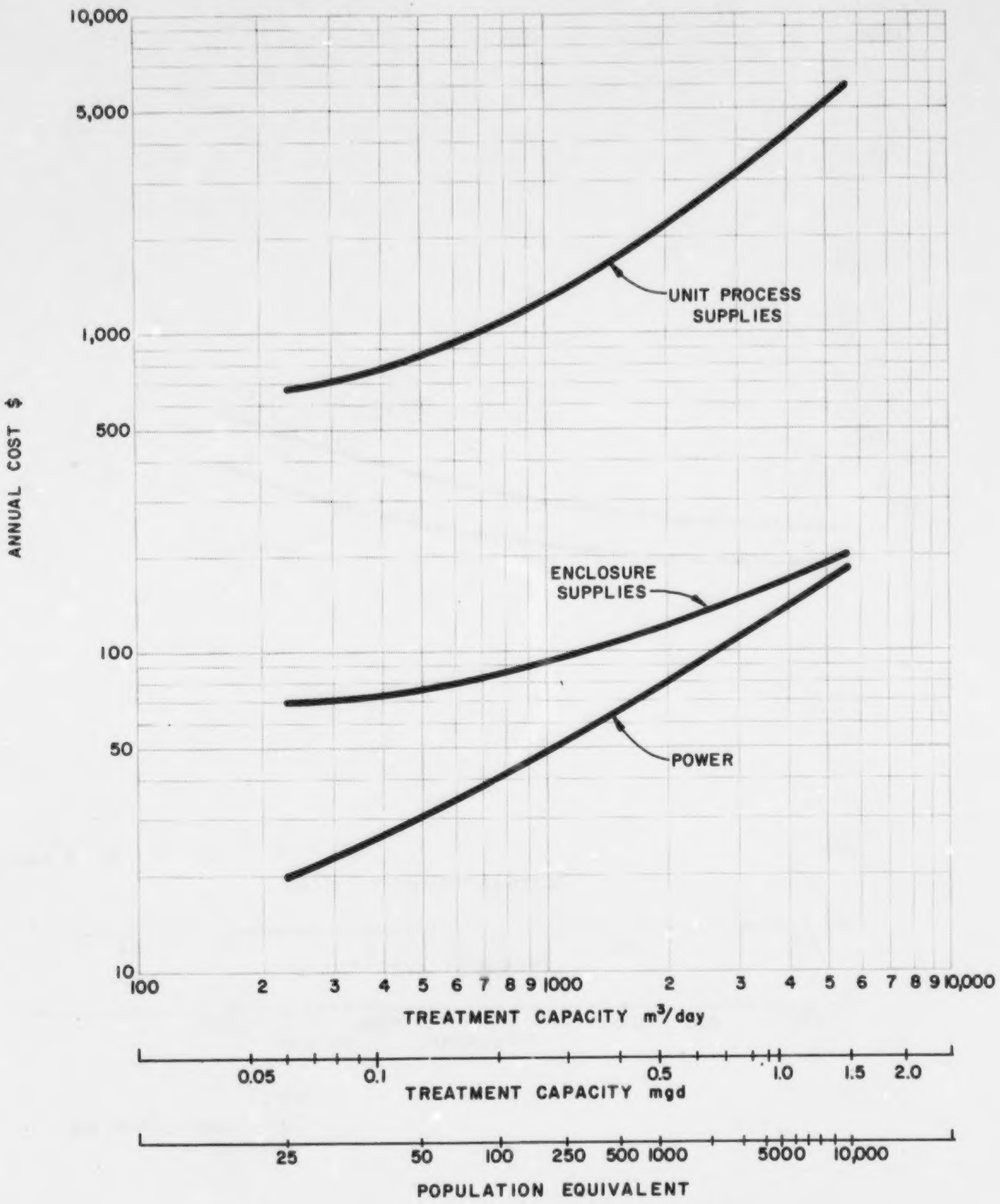


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

FLOCCULATOR - CLARIFIER
OPERATION AND MAINTENANCE COST

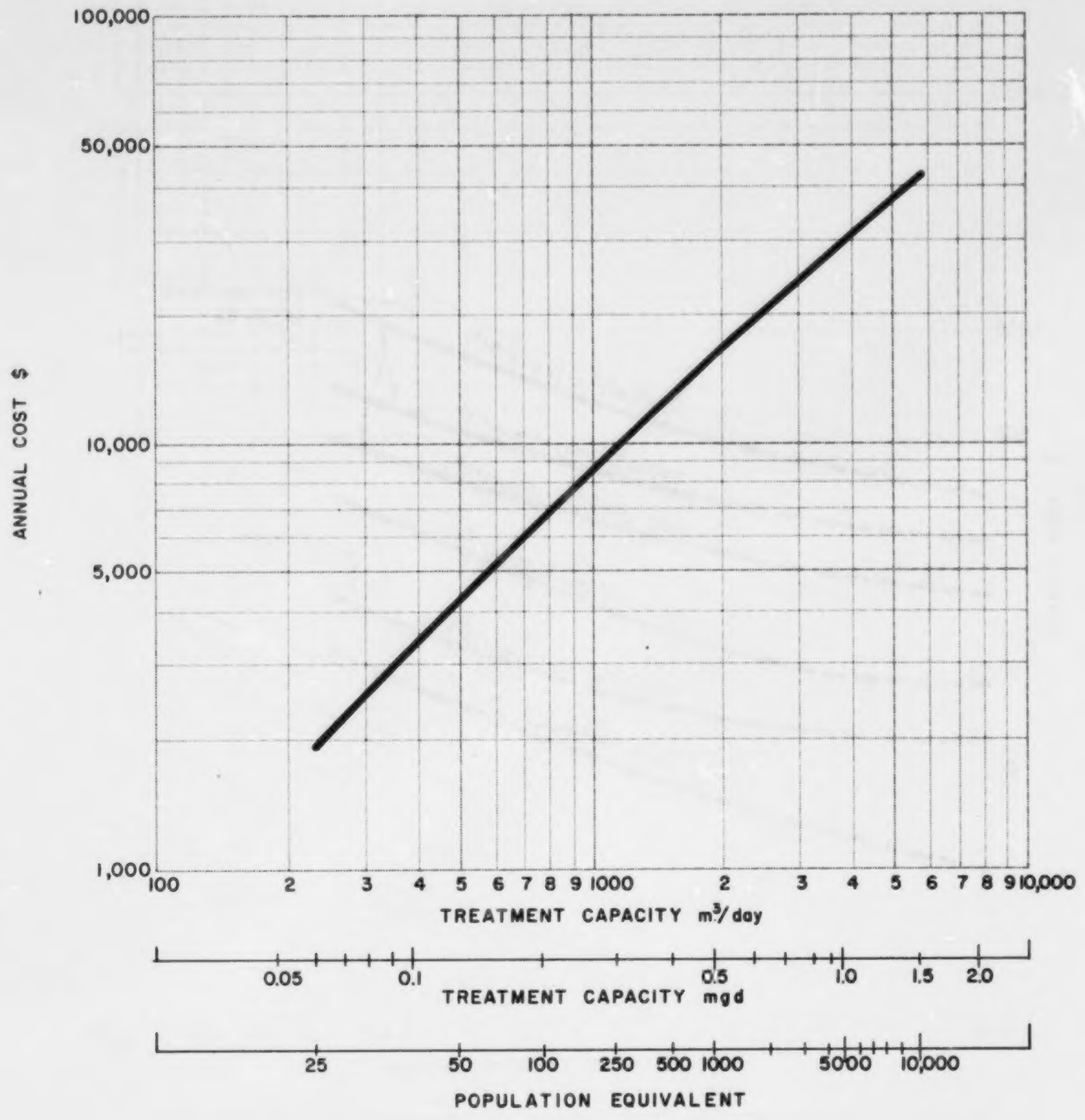
FIGURE 45



NOTE:
EXCLUDES LABOR. SEE PAGE VI-16.

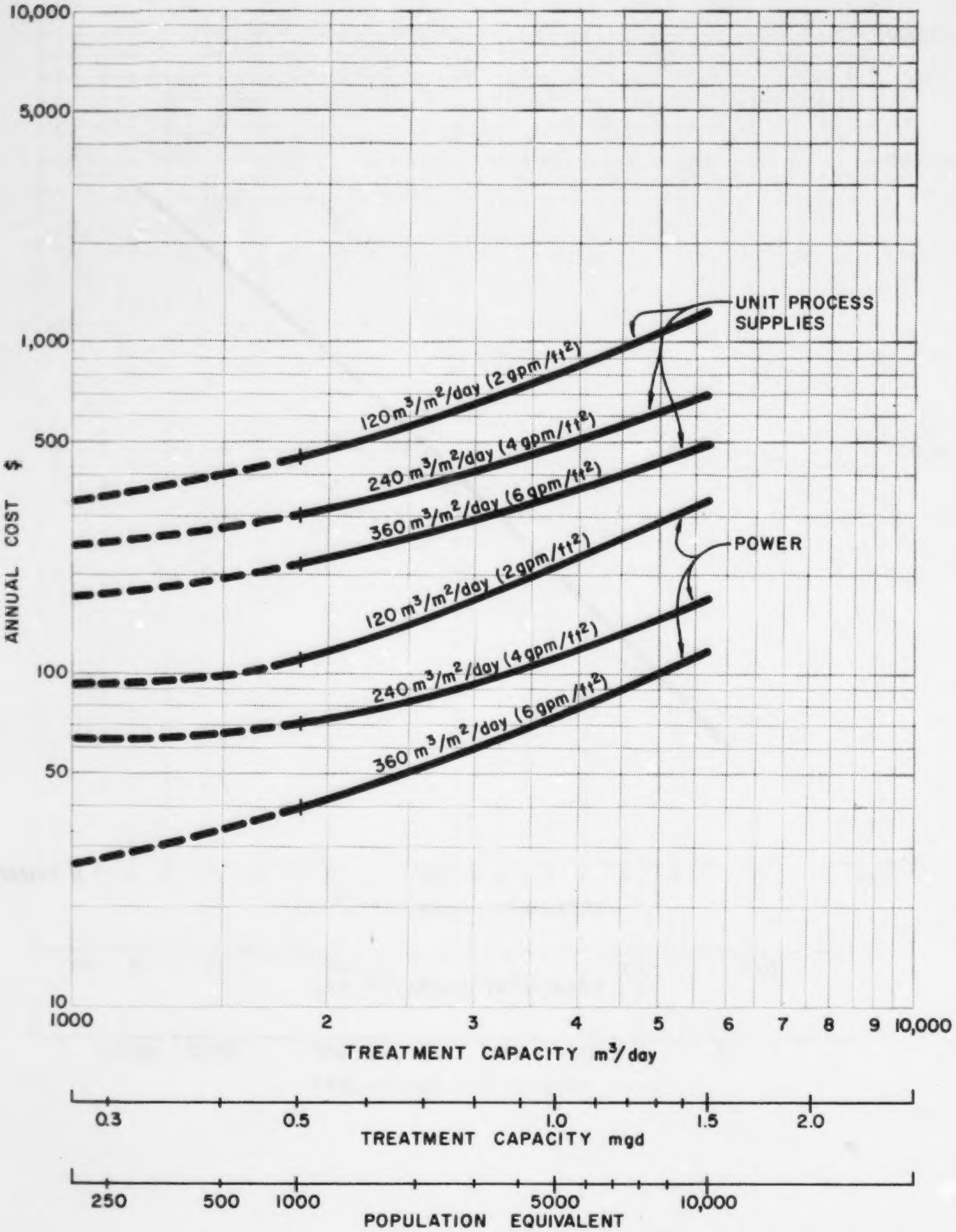
ION EXCHANGE SOFTENING
OPERATION AND MAINTENANCE COST

FIGURE 46



ION EXCHANGE SOFTENING
REGENERATIVE CHEMICAL COST

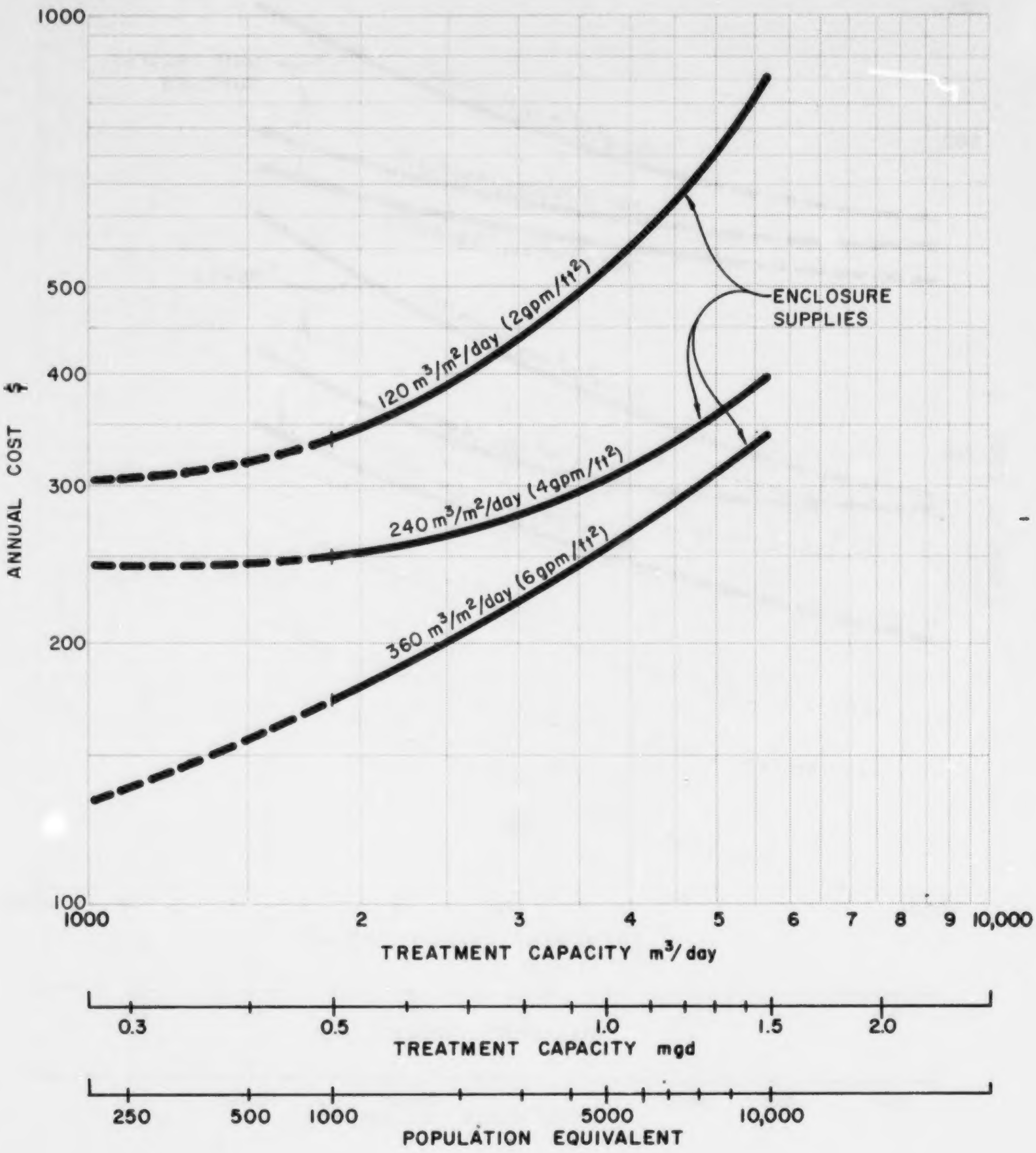
FIGURE 47



NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

PRESSURE FILTRATION
UNIT PROCESS
OPERATION AND MAINTENANCE COST

FIGURE 48



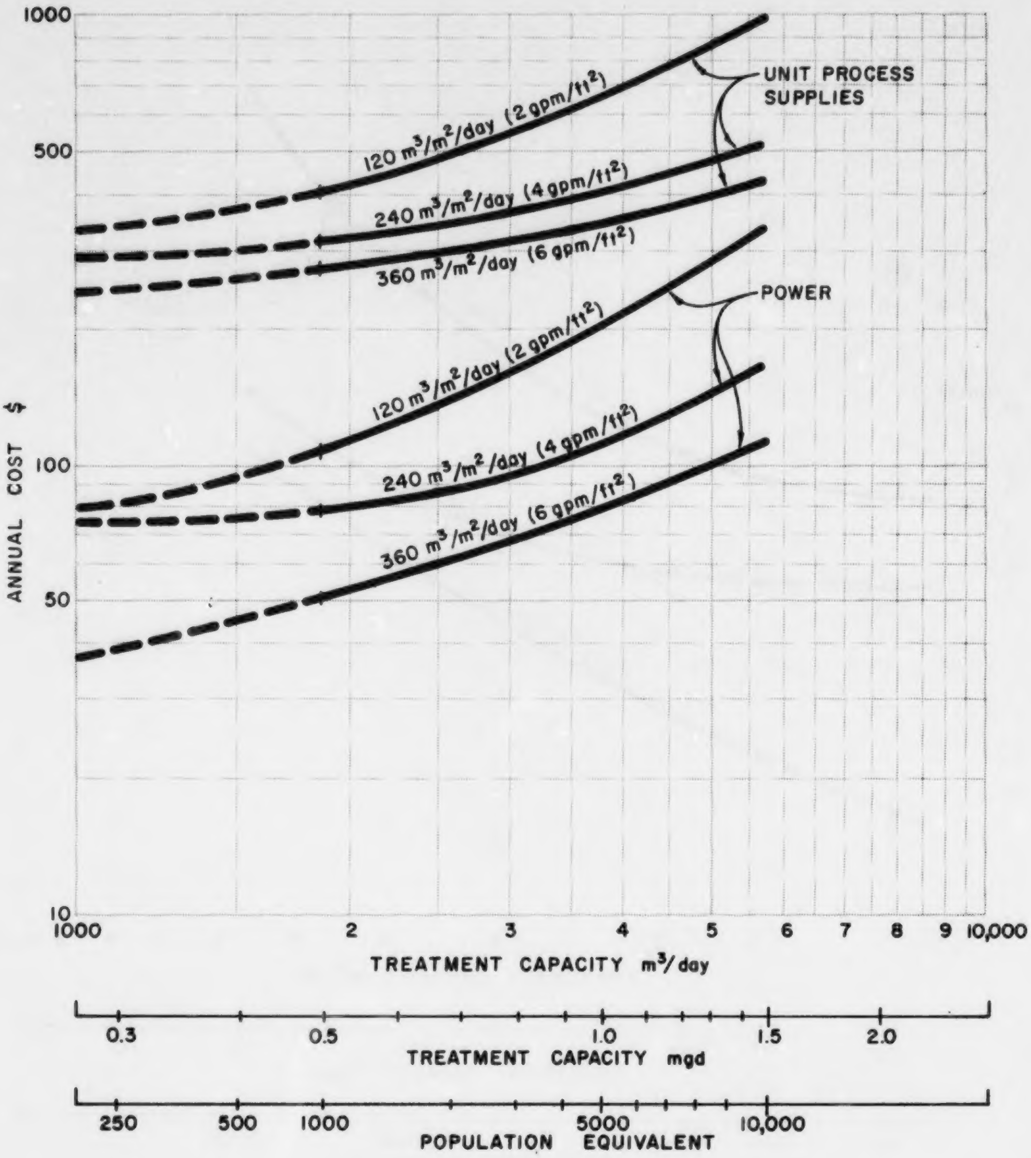
NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

PRESSURE FILTRATION ENCLOSURE

OPERATION AND MAINTENANCE COST

FIGURE 49

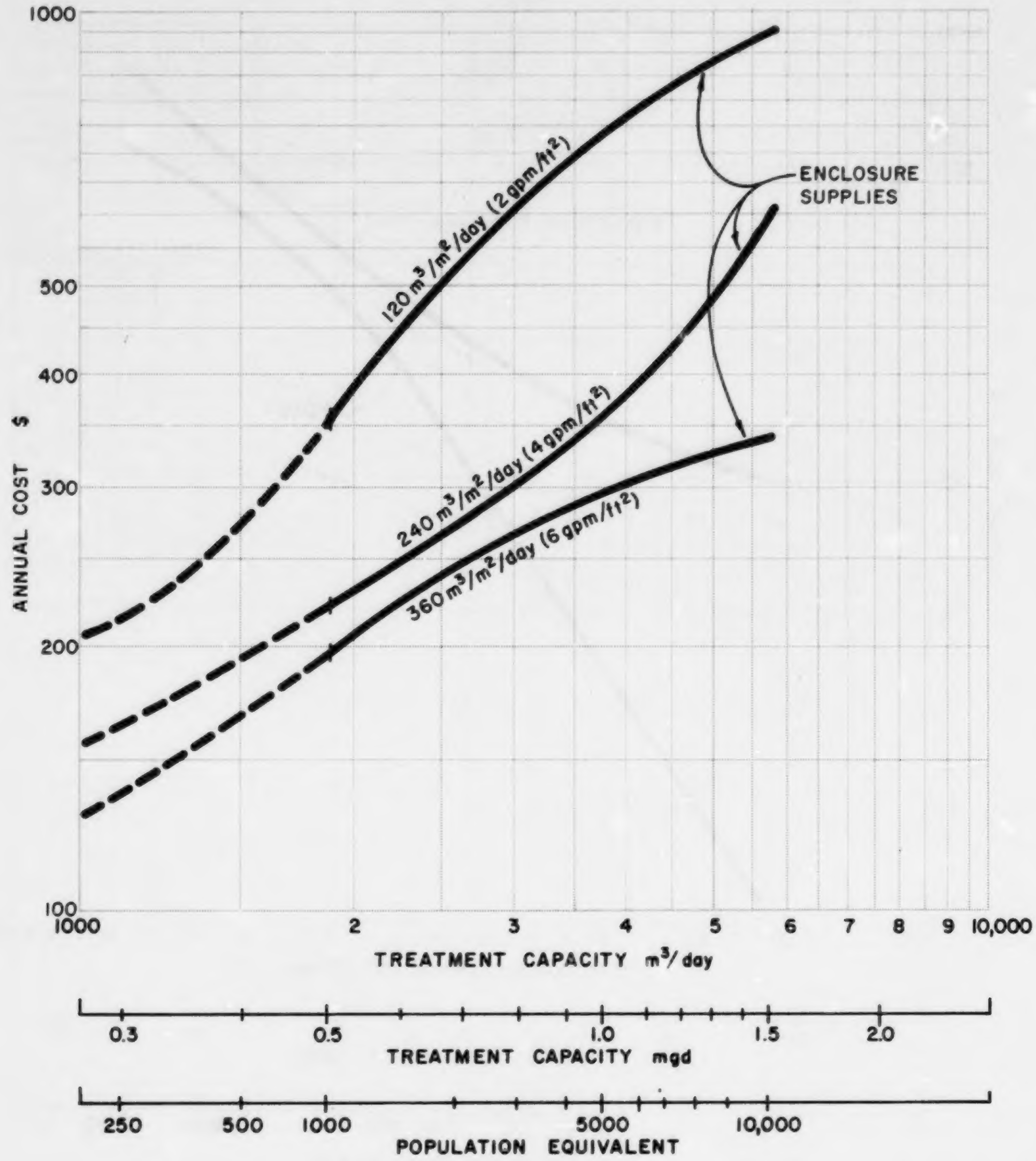


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

GRAVITY FILTRATION
UNIT PROCESS
OPERATION AND MAINTENANCE COST

FIGURE 50



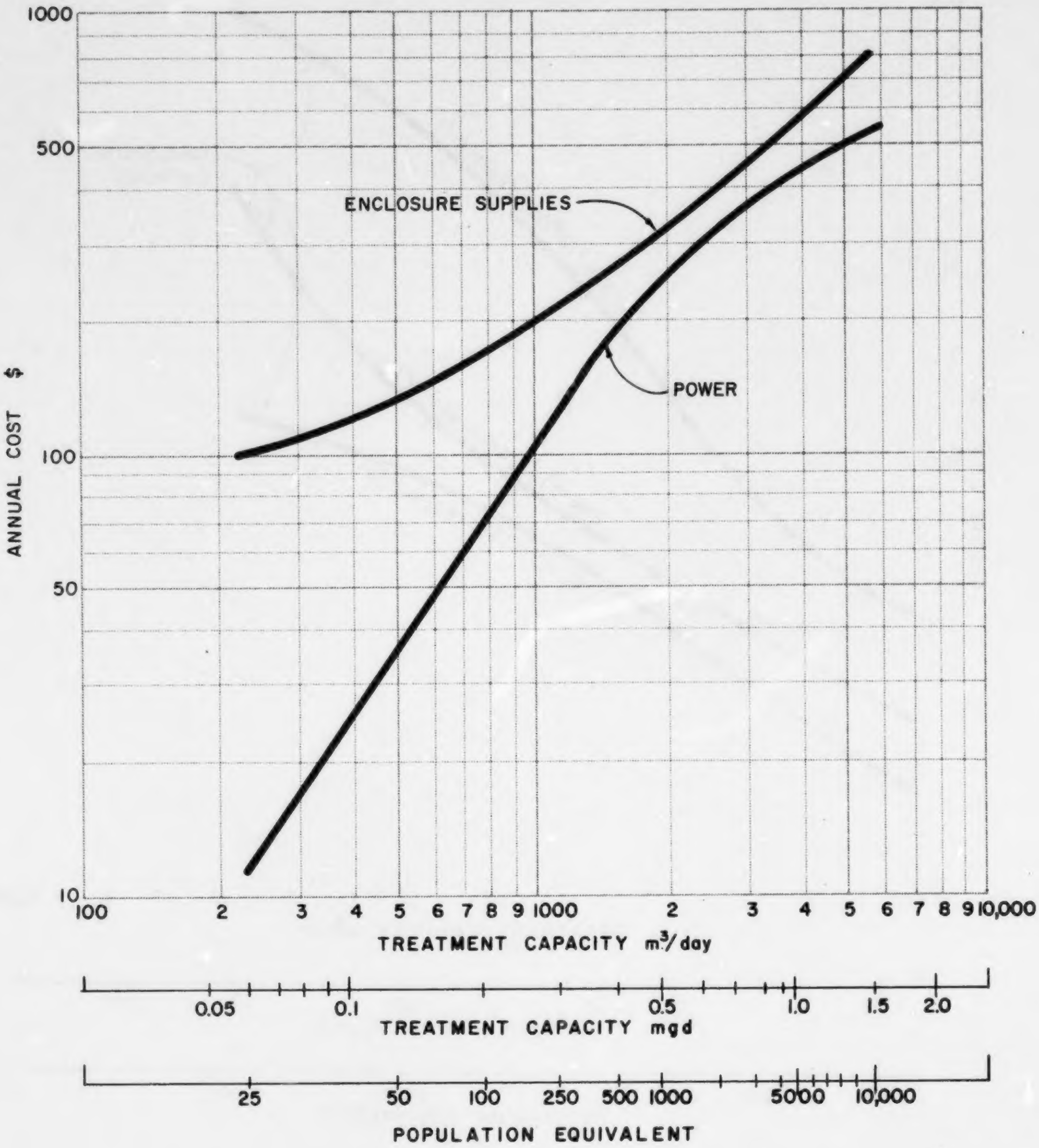
NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

GRAVITY FILTRATION
ENCLOSURE

OPERATION AND MAINTENANCE COST

FIGURE 51



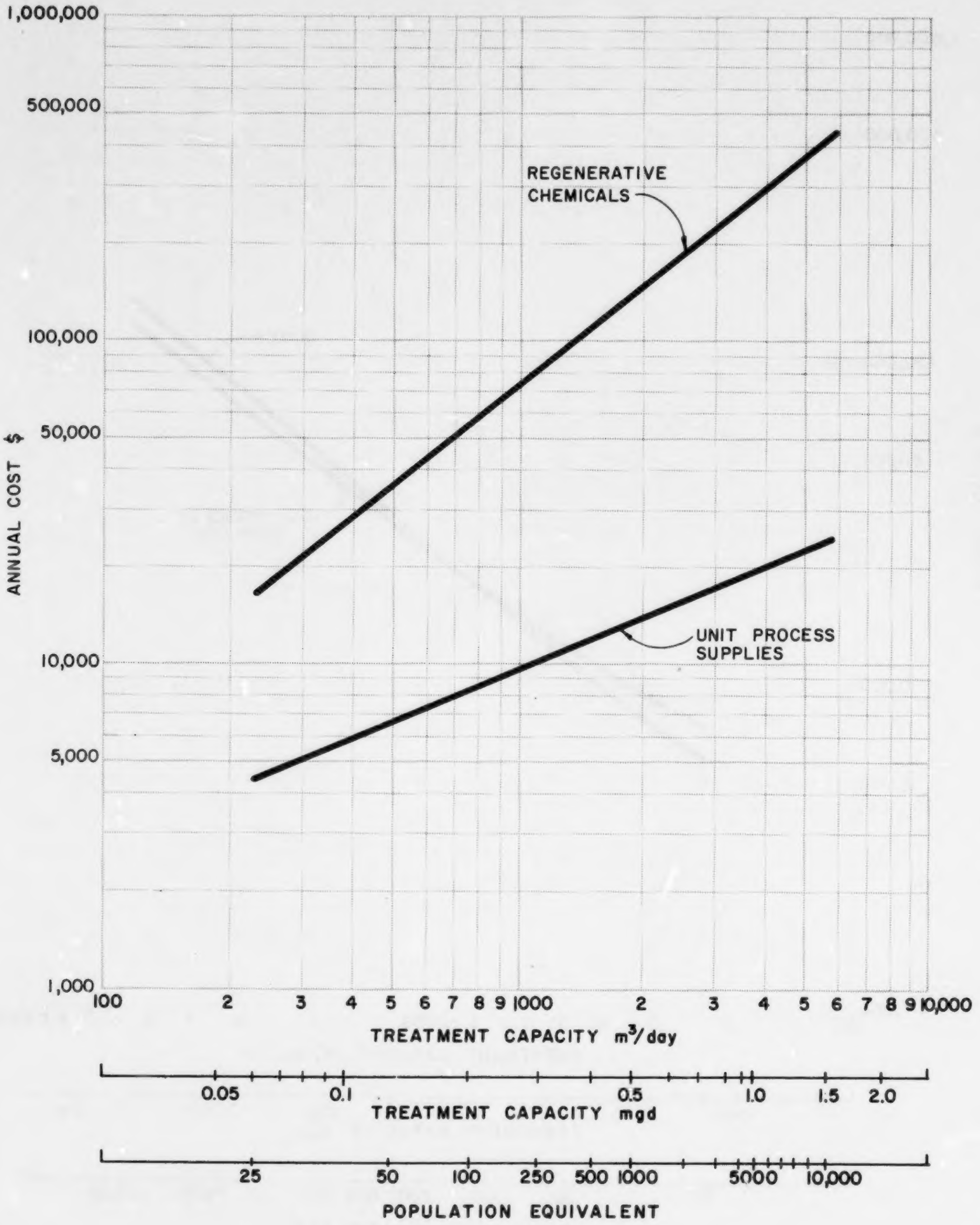
NOTE:

EXCLUDES LABOR. SEE PAGE VI - 16.

DEMINERALIZATION
POWER AND ENCLOSURE SUPPLIES

OPERATION AND MAINTENANCE COST

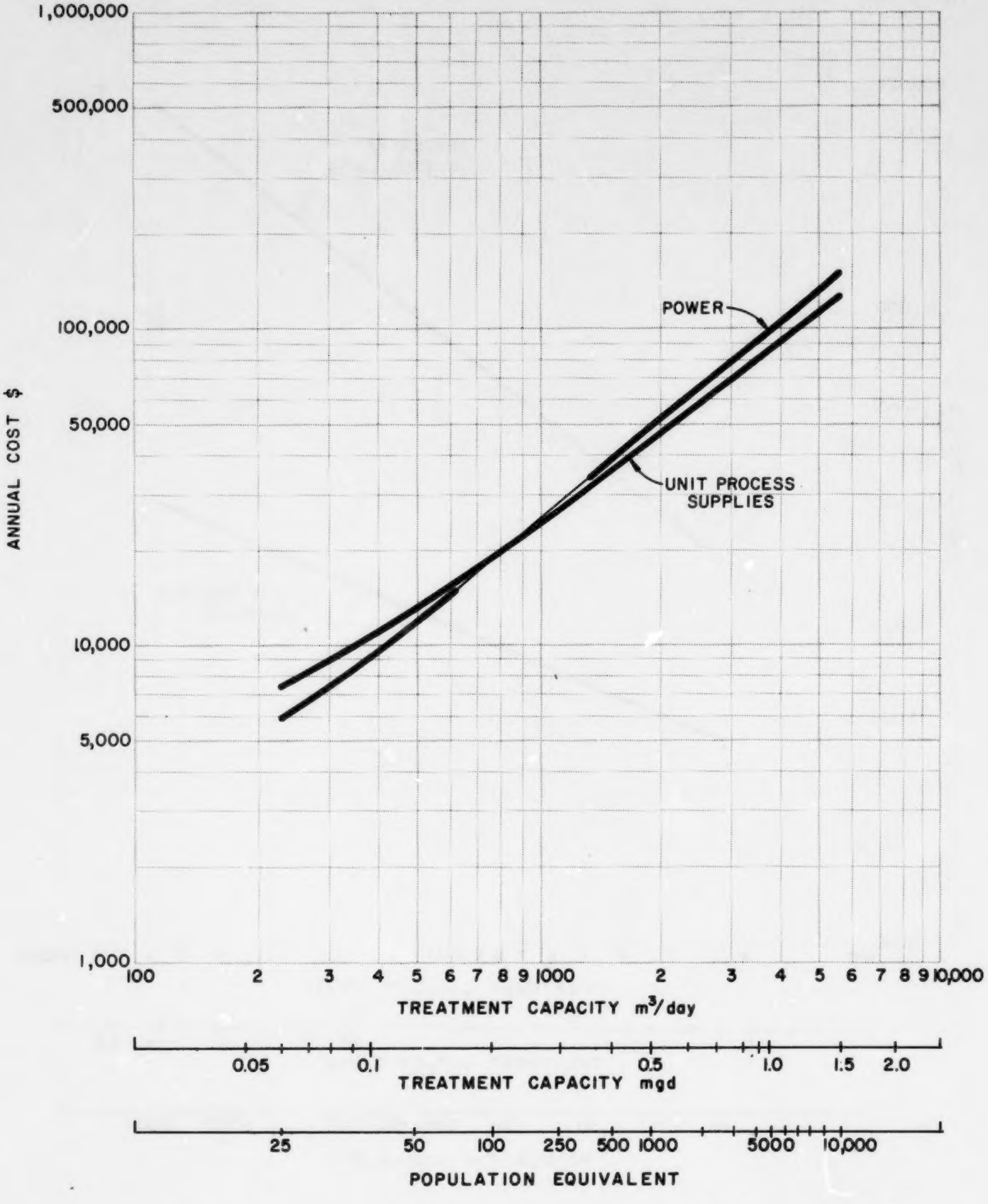
FIGURE 52



DEMINERALIZATION
UNIT PROCESS SUPPLIES
AND REGENERATIVE CHEMICALS

OPERATION AND MAINTENANCE COST

FIGURE 53



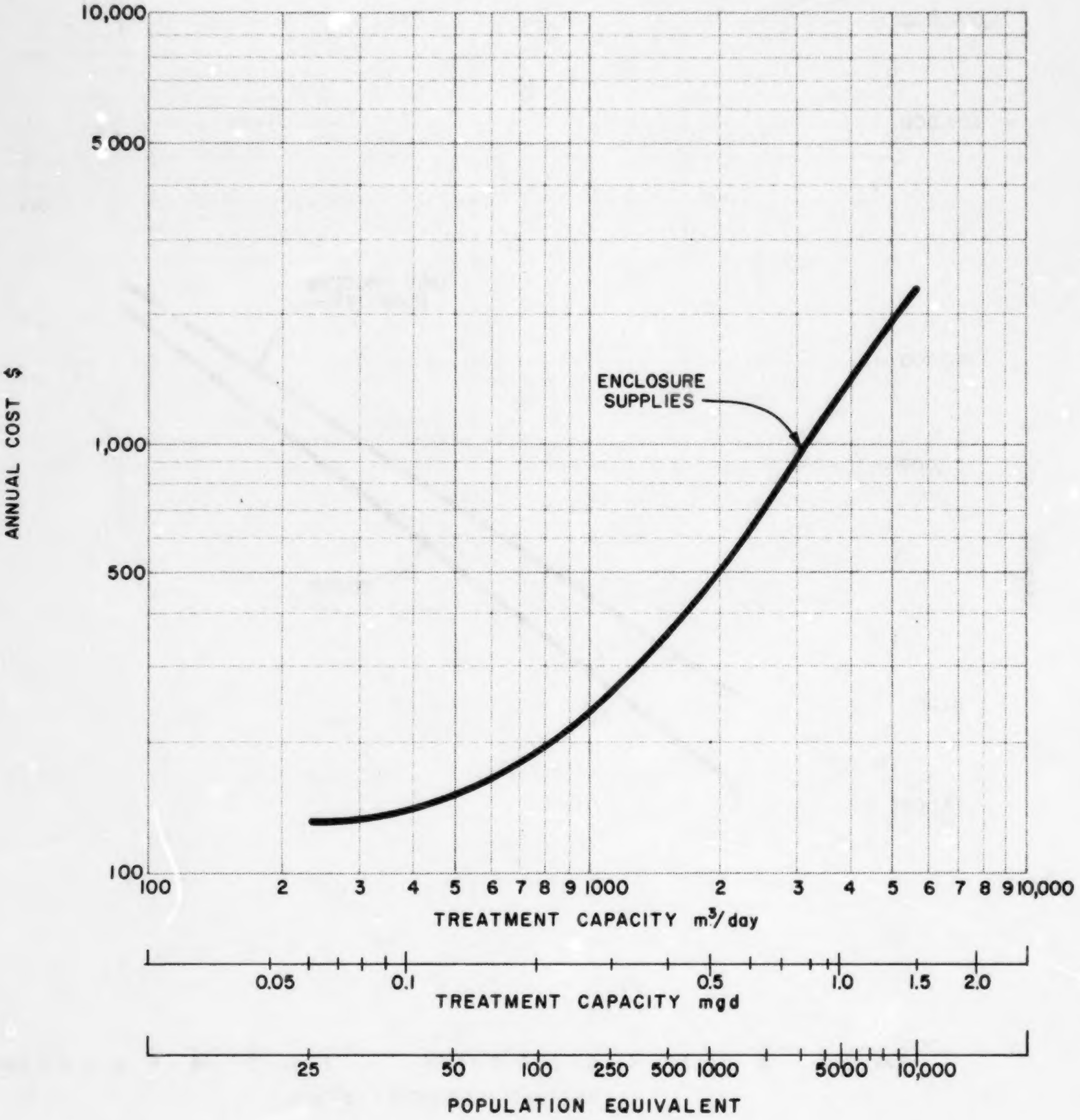
NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

ELECTRODIALYSIS UNIT PROCESS

OPERATION AND MAINTENANCE COST

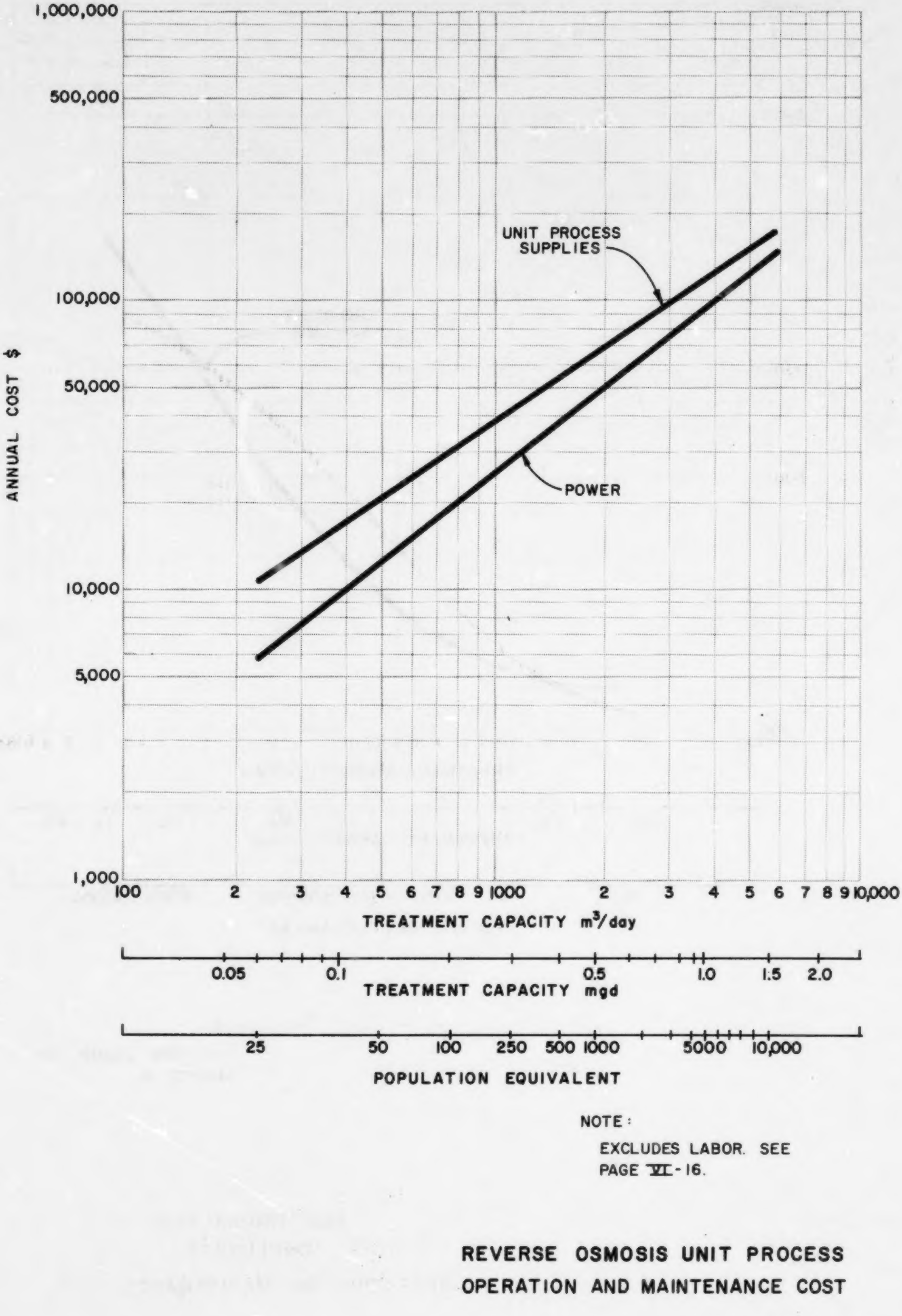
FIGURE 54



NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

ELECTRODIALYSIS
ENCLOSURE
OPERATION AND MAINTENANCE COST

FIGURE 55

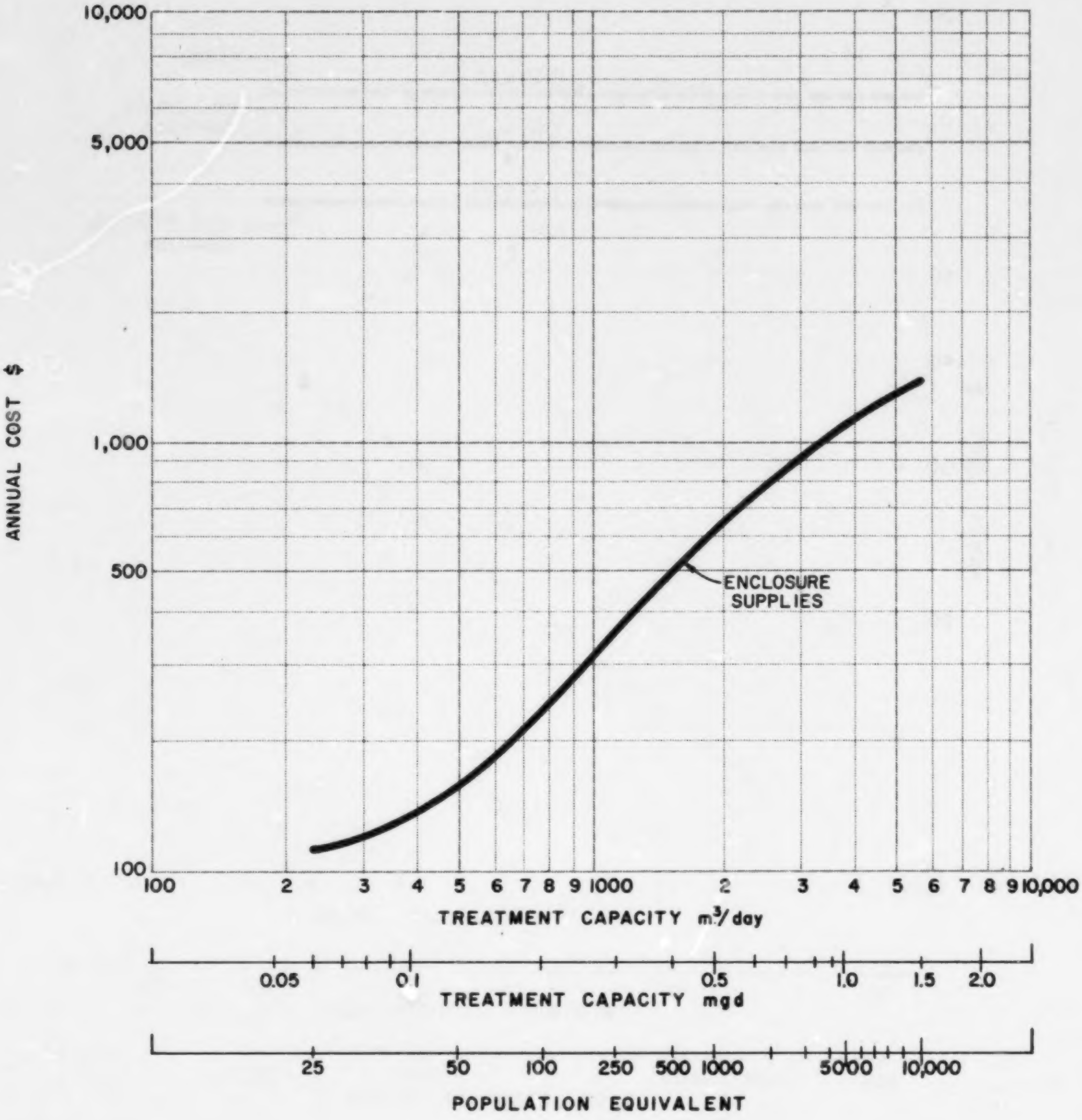


NOTE:

EXCLUDES LABOR. SEE PAGE VI - 16.

REVERSE OSMOSIS UNIT PROCESS
OPERATION AND MAINTENANCE COST

FIGURE 56

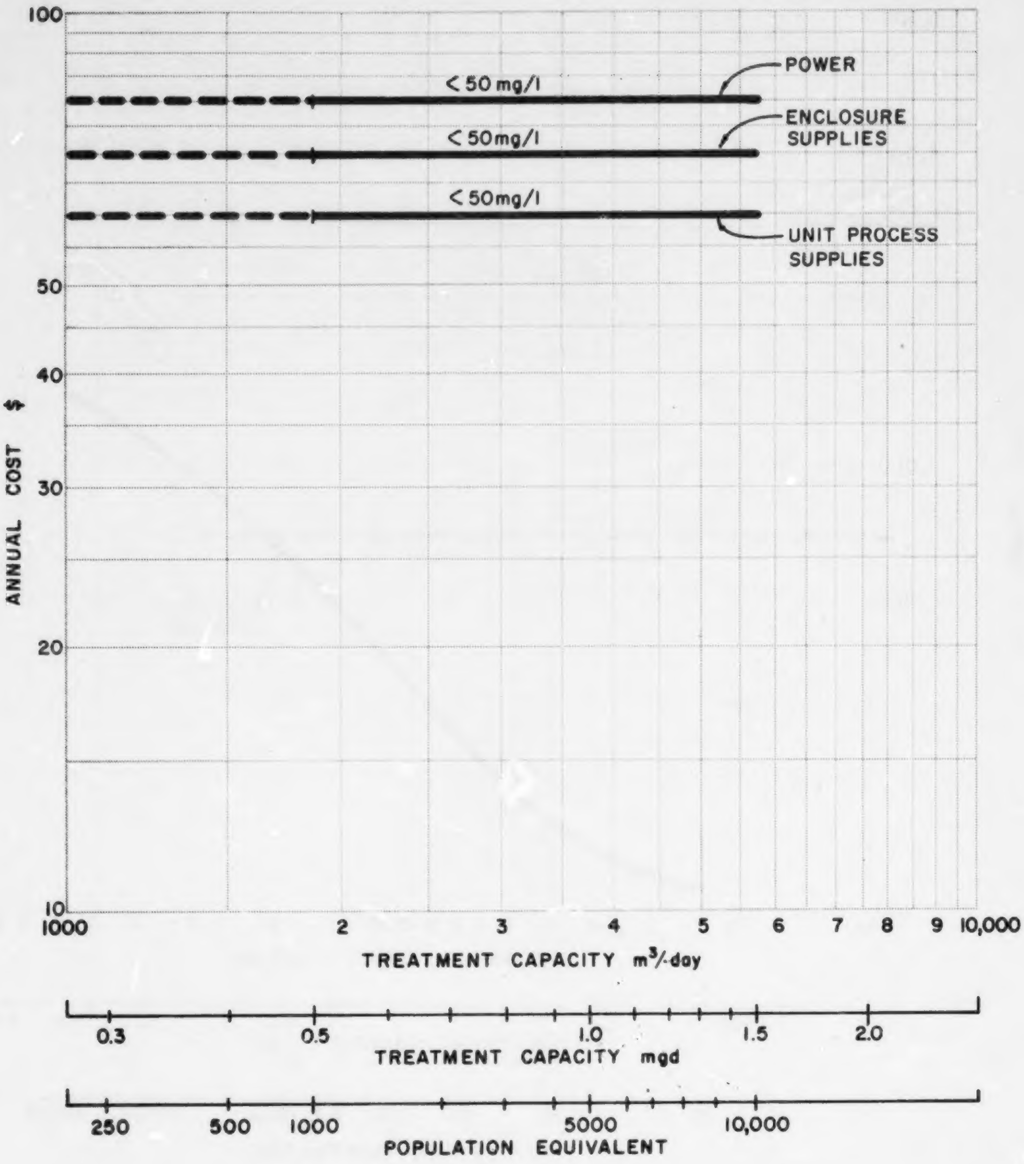


NOTE :

EXCLUDES LABOR. SEE PAGE VI -16.

REVERSE OSMOSIS ENCLOSURE
OPERATION AND MAINTENANCE COST

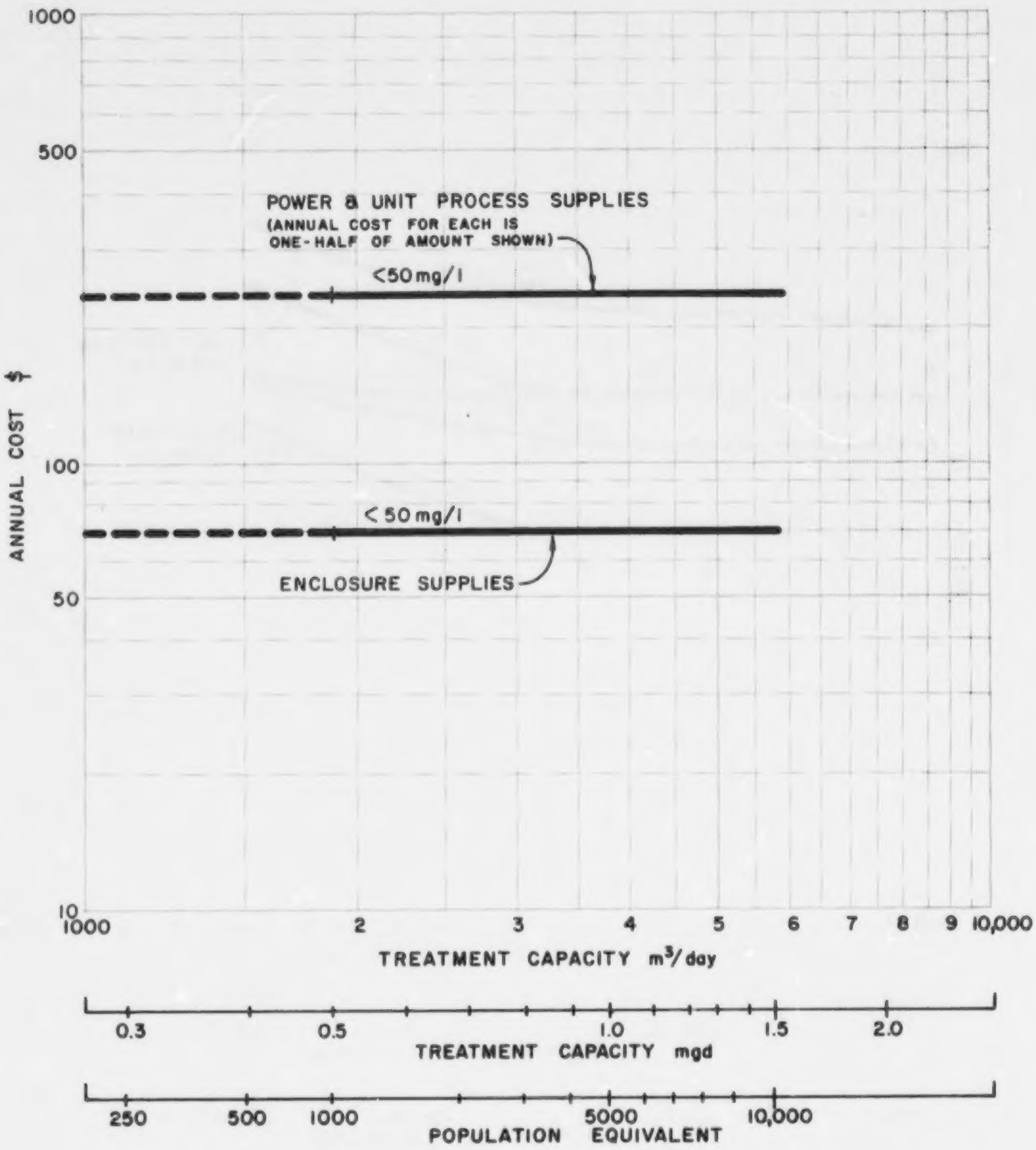
FIGURE 57



NOTE:
EXCLUDES LABOR. SEE
PAGE VI - 16.

POWDERED ACTIVATED CARBON
CHEMICAL FEED
OPERATION AND MAINTENANCE COST

FIGURE 58

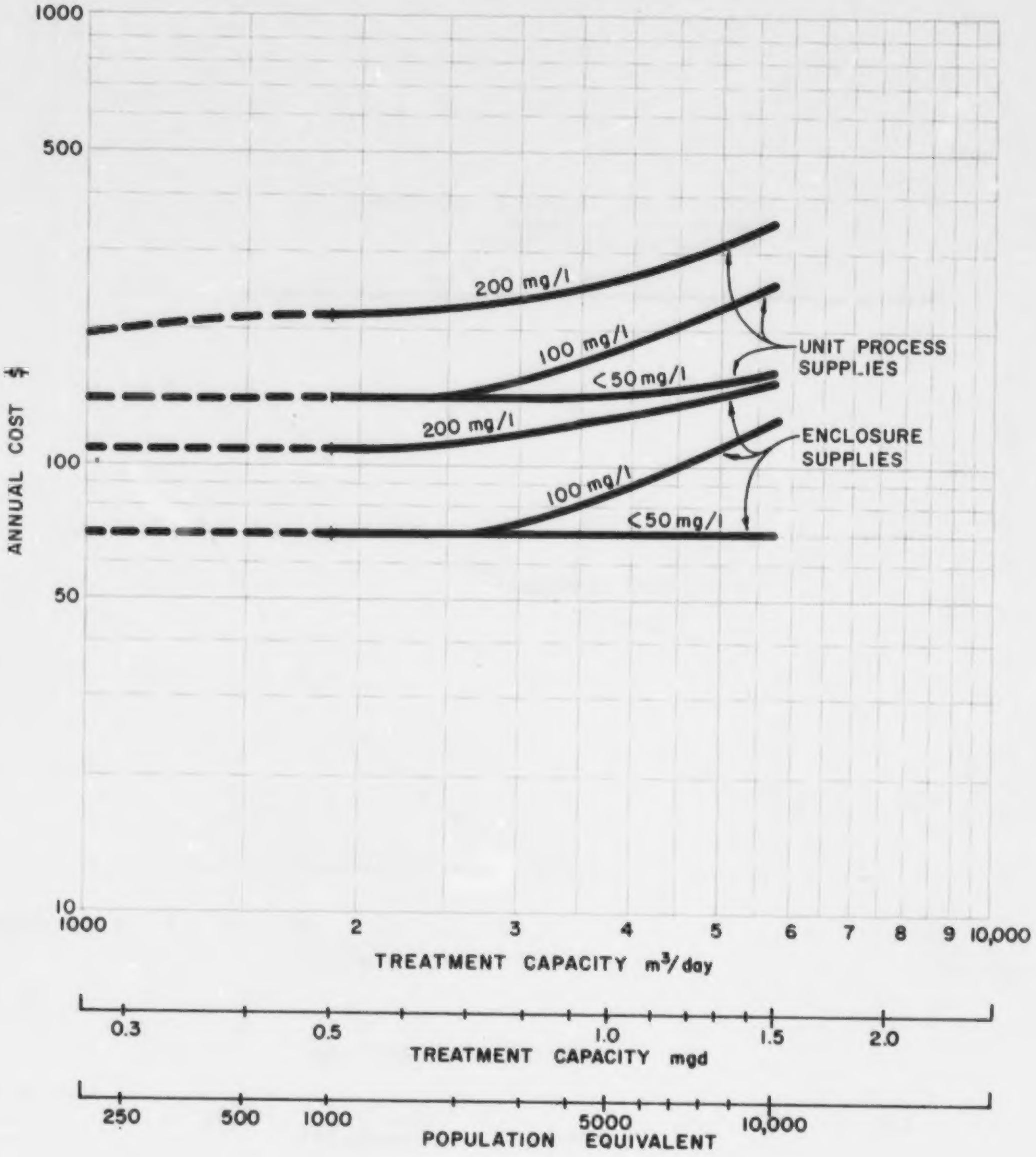


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16

COAGULANT
CHEMICAL FEED
OPERATION AND MAINTENANCE COST

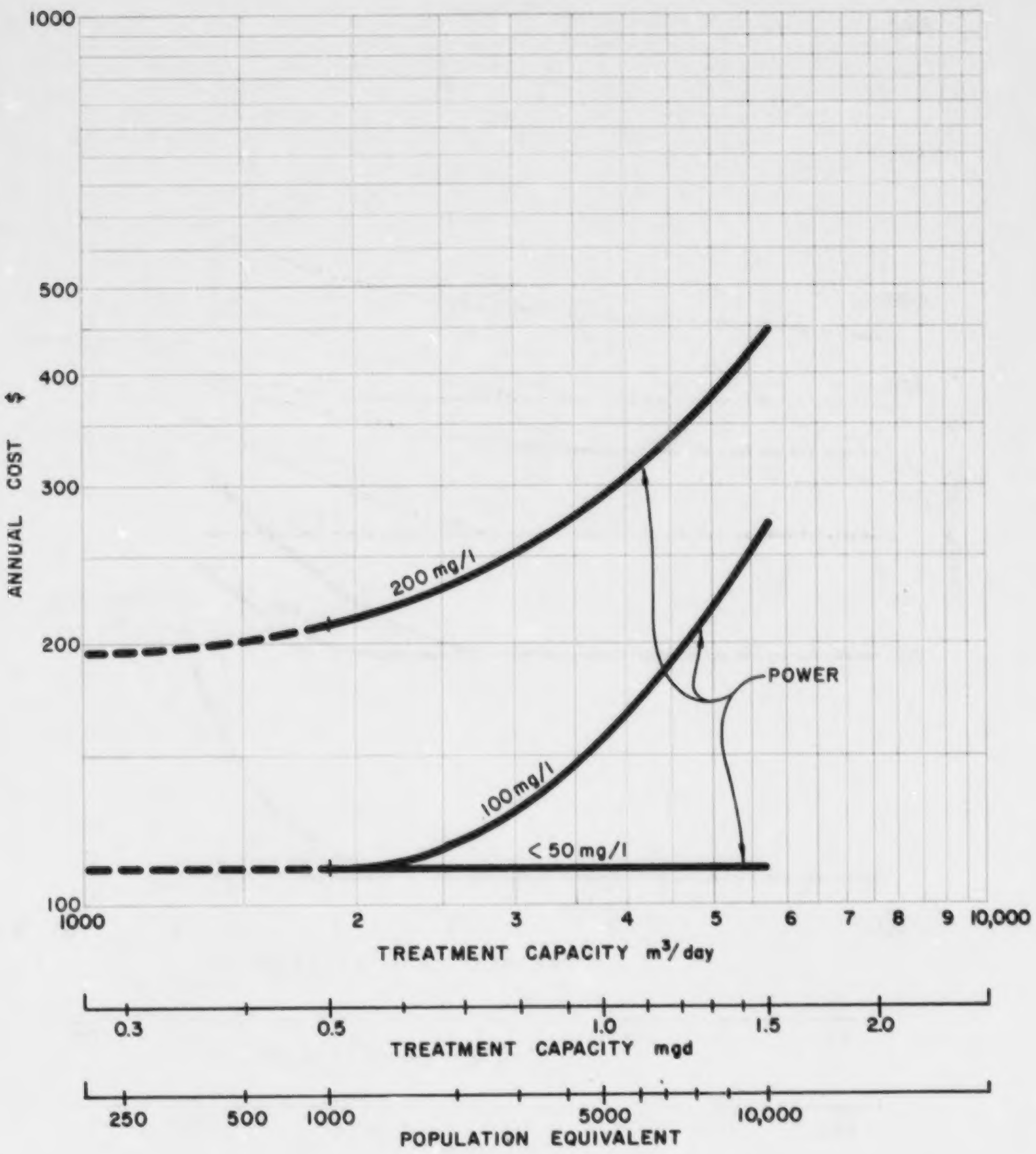
FIGURE 59



NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

HYDRATED LIME
CHEMICAL FEED SUPPLIES
OPERATION AND MAINTENANCE COST

FIGURE 60



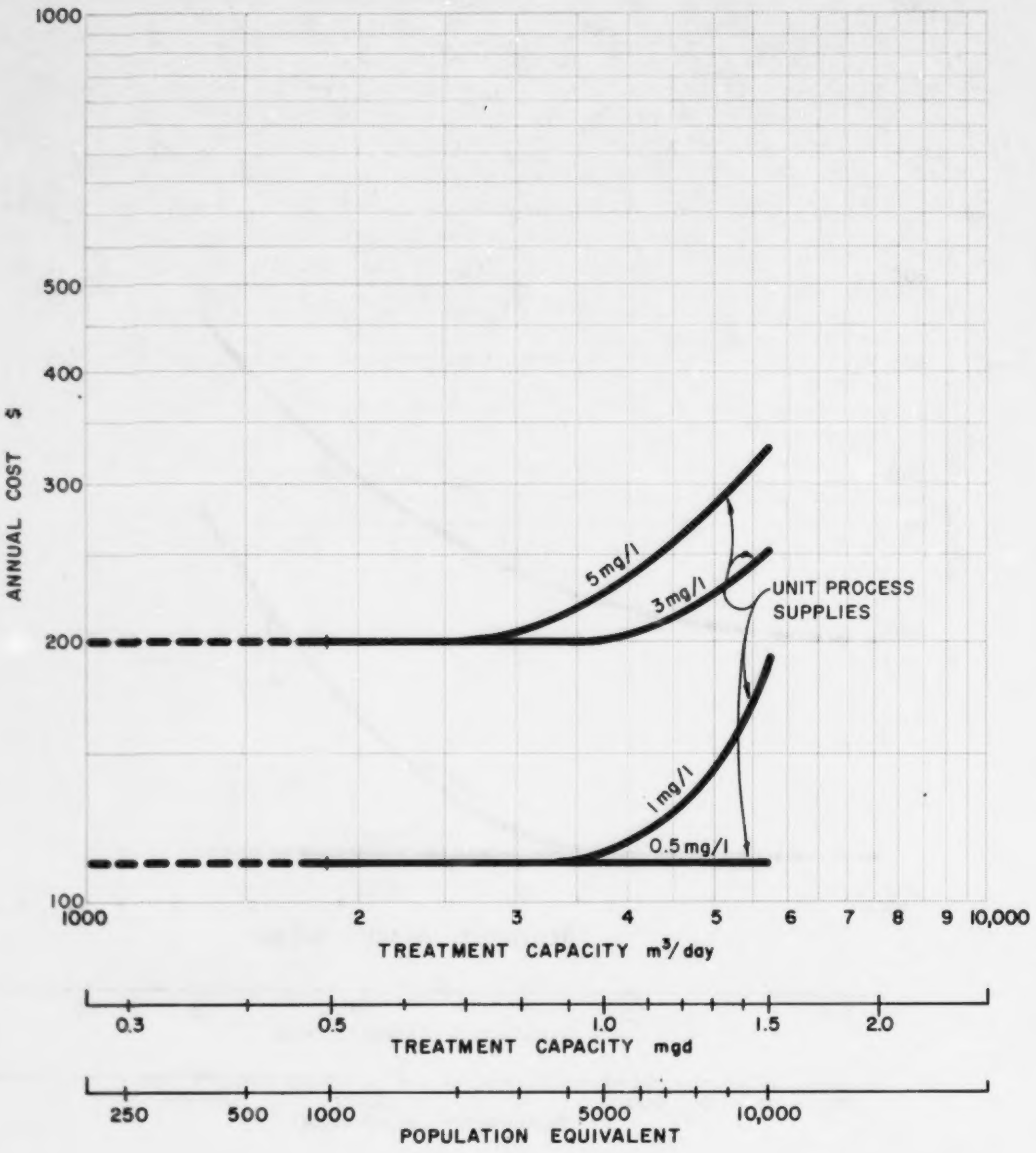
NOTE :

EXCLUDES LABOR. SEE PAGE VI-16.

HYDRATED LIME
CHEMICAL FEED
POWER

OPERATION AND MAINTENANCE COST

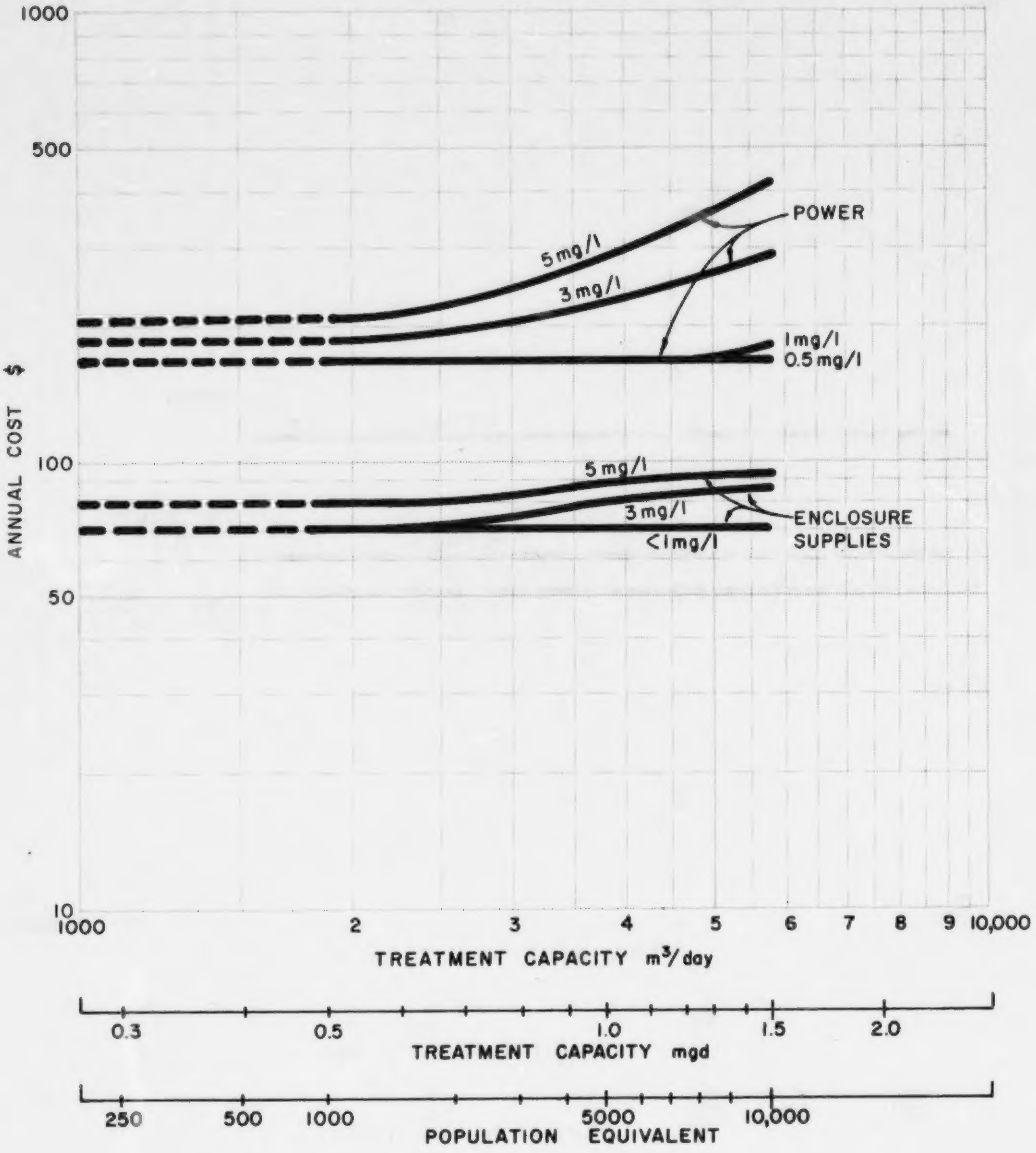
FIGURE 61



NOTE:
EXCLUDES LABOR. SEE PAGE VI - 16.

POLYMER
CHEMICAL FEED
UNIT PROCESS
OPERATION AND MAINTENANCE COST

FIGURE 62



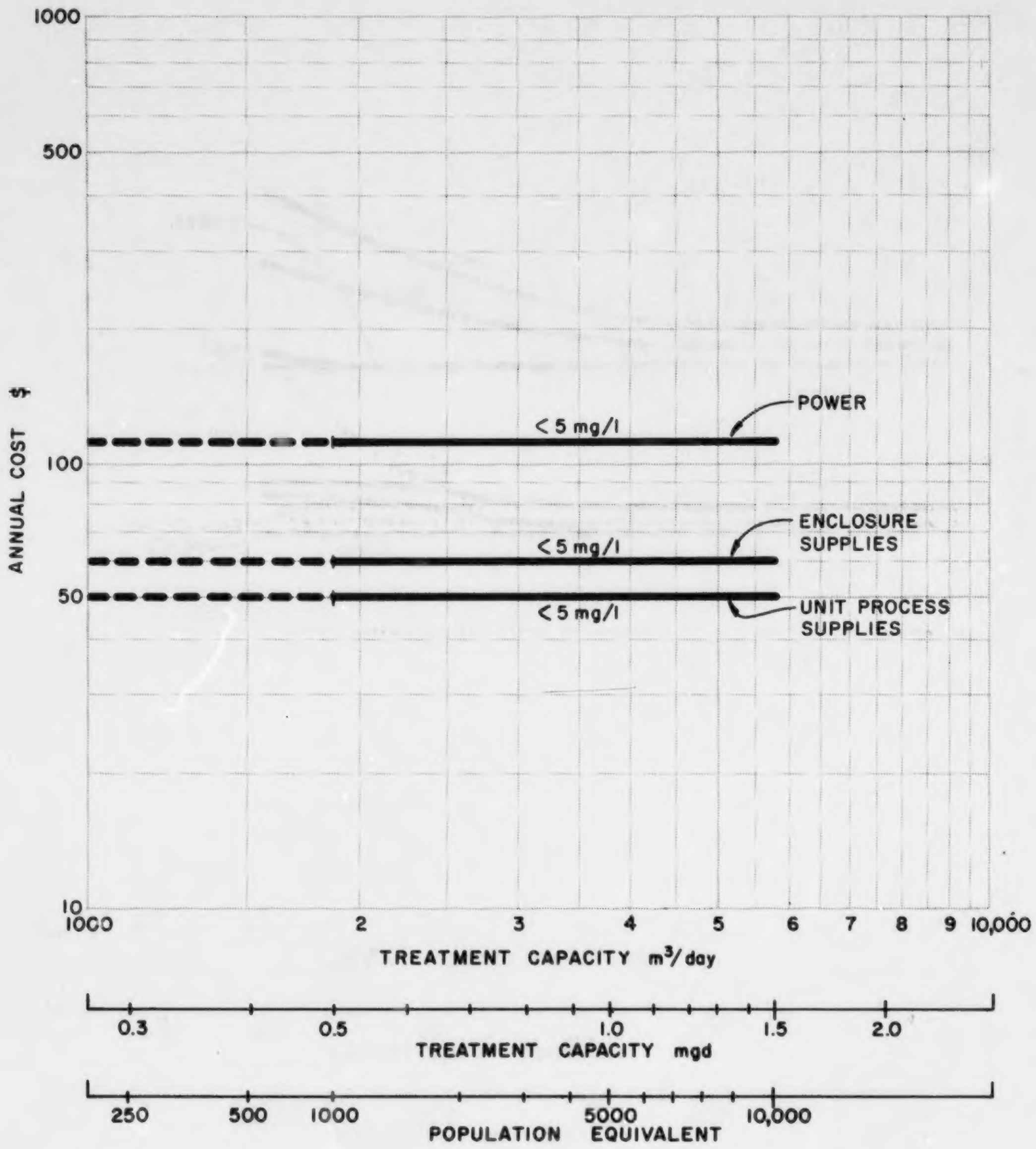
NOTE :

EXCLUDES LABOR. SEE PAGE VI - 16.

POLYMER
CHEMICAL FEED
POWER AND ENCLOSURE

OPERATION AND MAINTENANCE COST

FIGURE 63



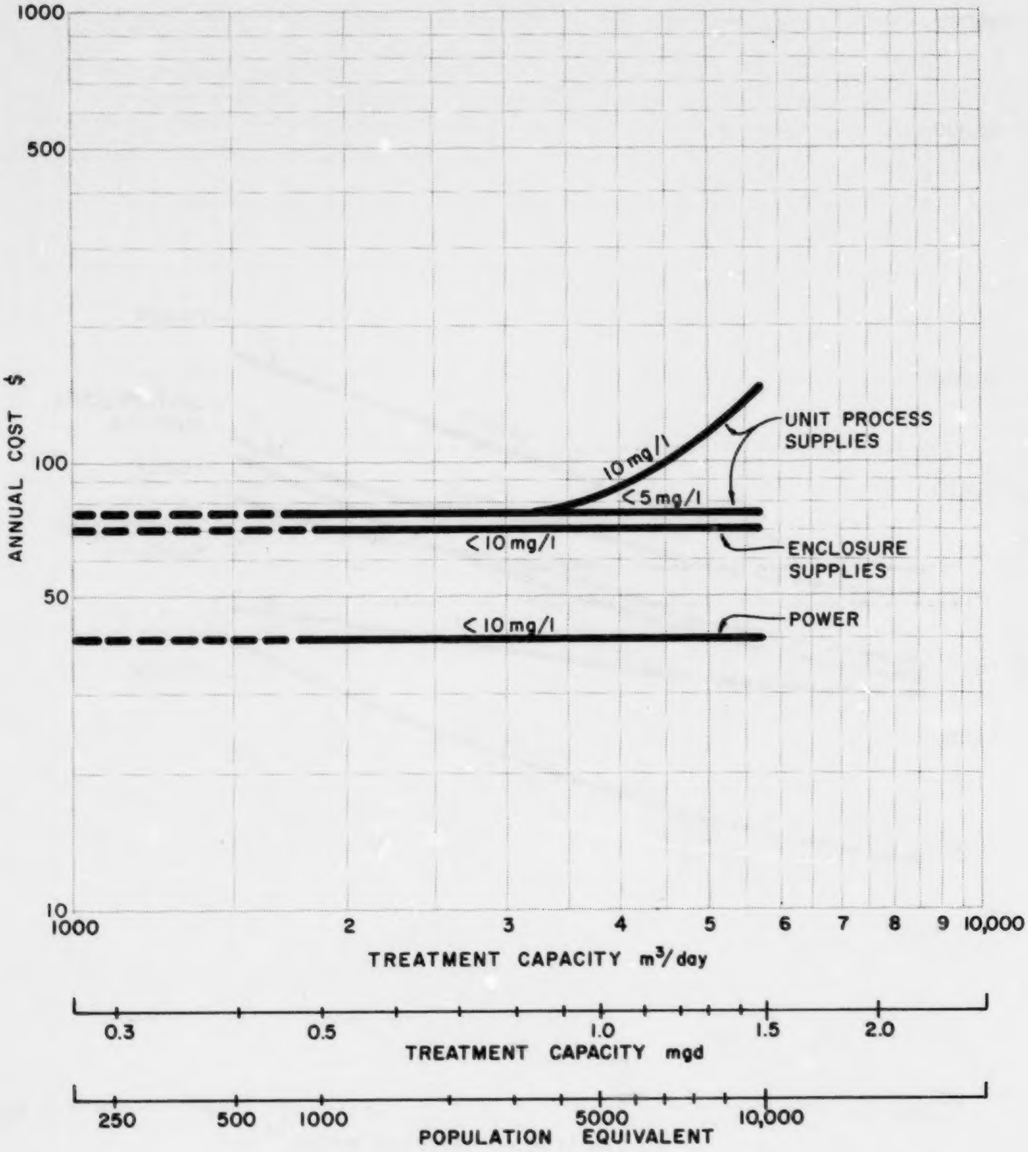
NOTE:

EXCLUDES LABOR SEE PAGE VI-16.

POLYPHOSPHATE CHEMICAL FEED

OPERATION AND MAINTENANCE COST

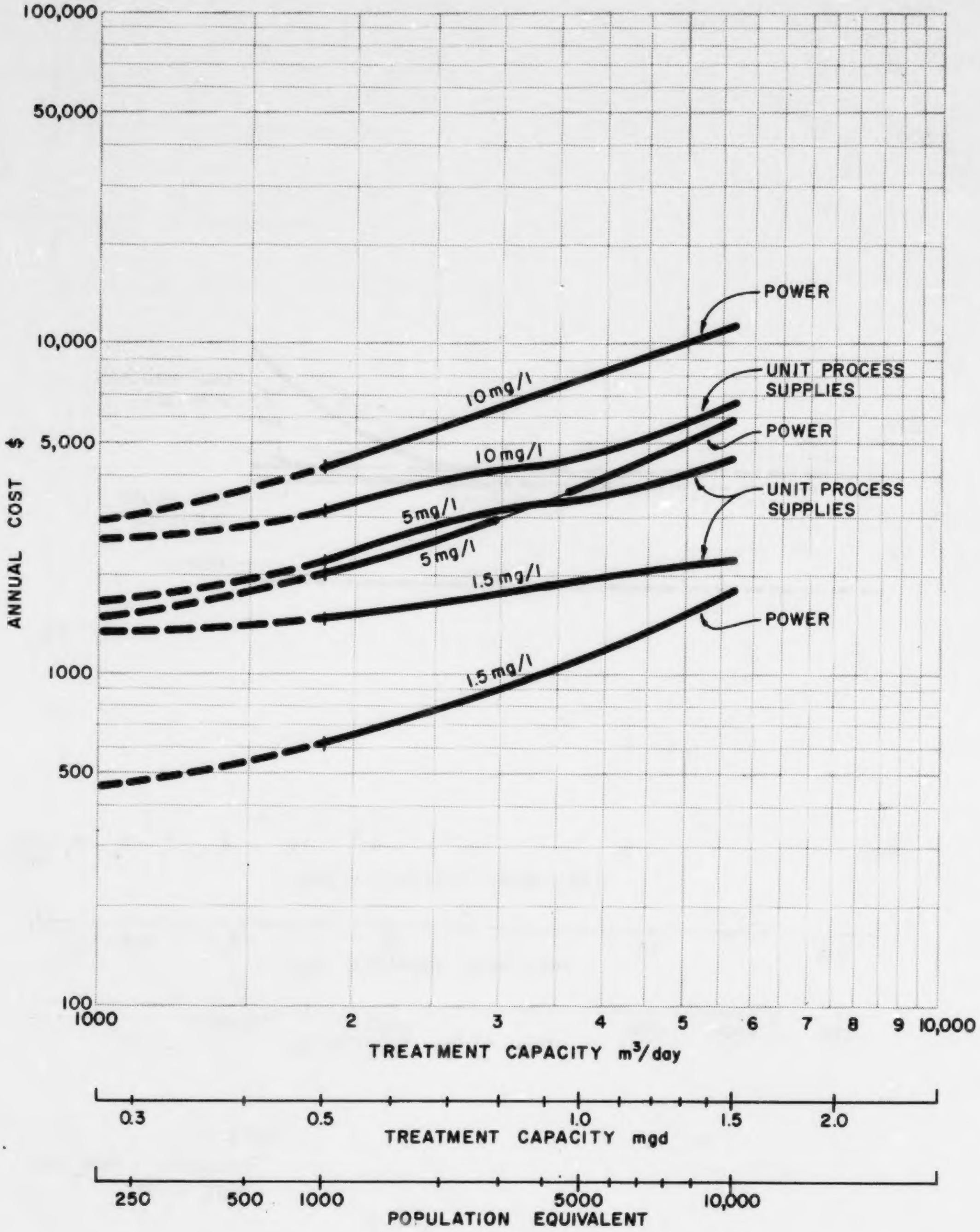
FIGURE 64



NOTE :
EXCLUDES LABOR. SEE PAGE VI-16.

CHLORINE
CHEMICAL FEED
OPERATION AND MAINTENANCE COST

FIGURE 65

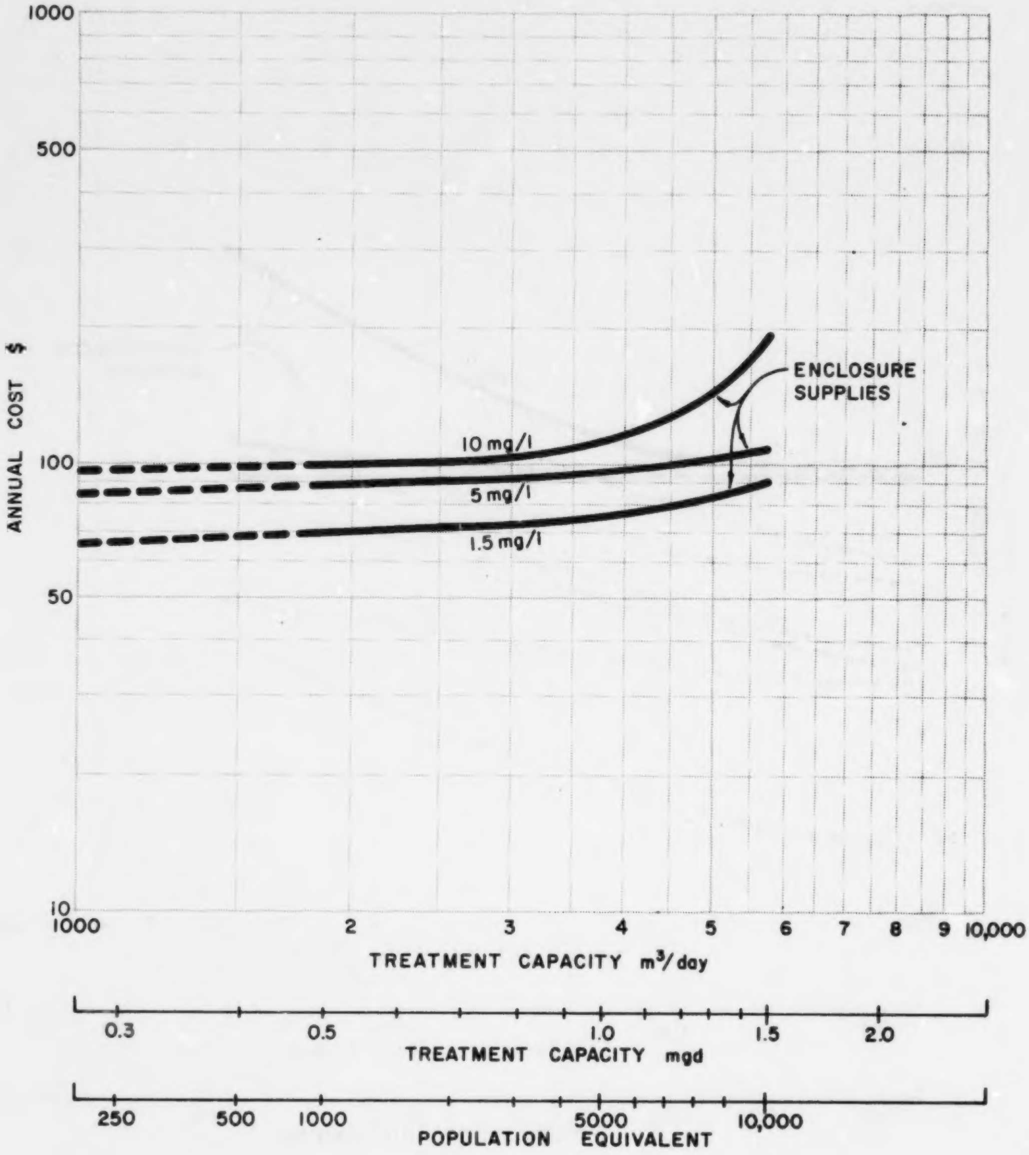


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

OZONE
ON-SITE GENERATION
UNIT PROCESS
OPERATION AND MAINTENANCE COST

FIGURE 66

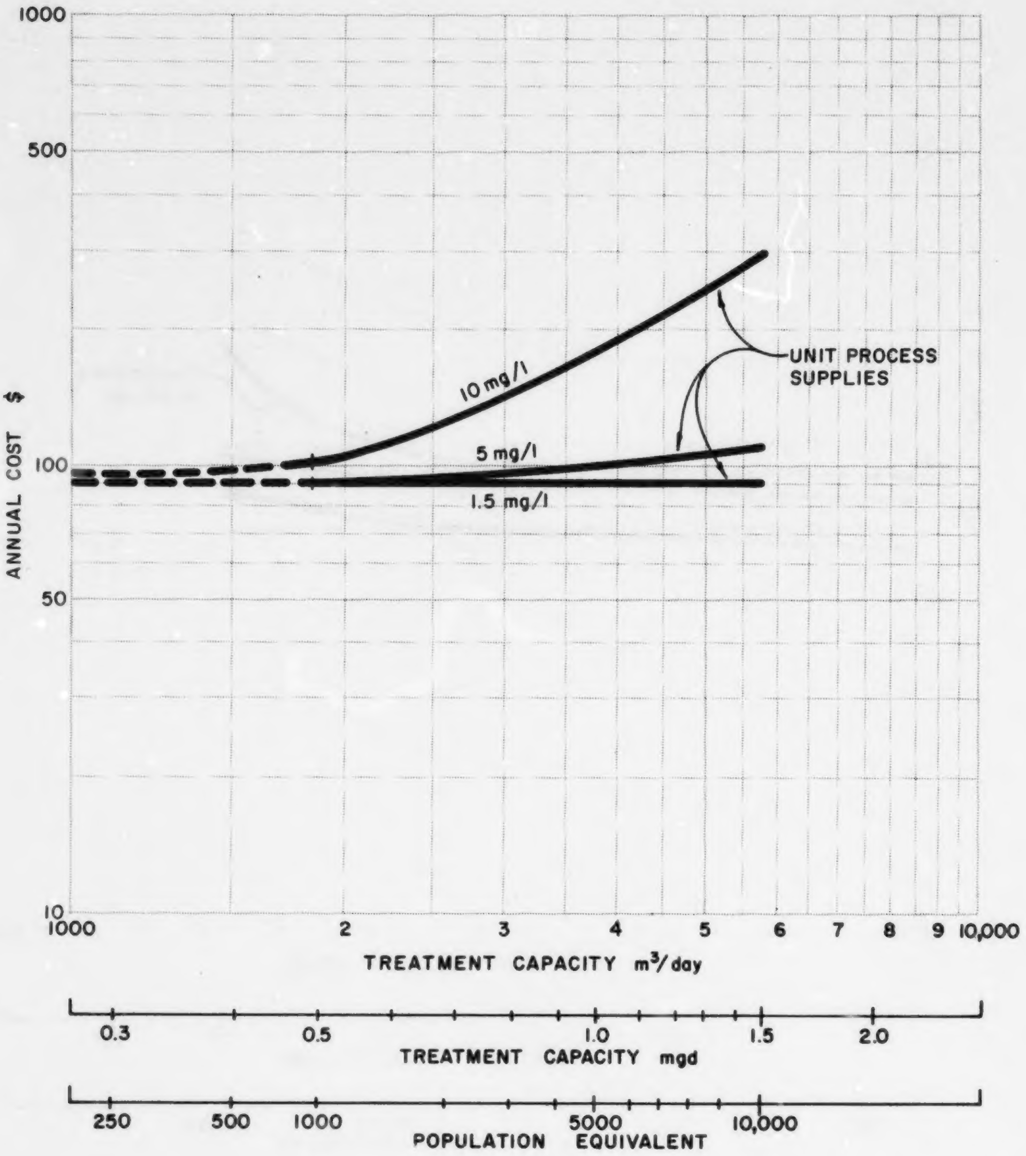


NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

OZONE
ON-SITE GENERATION
ENCLOSURE
OPERATION AND MAINTENANCE COST

FIGURE 67

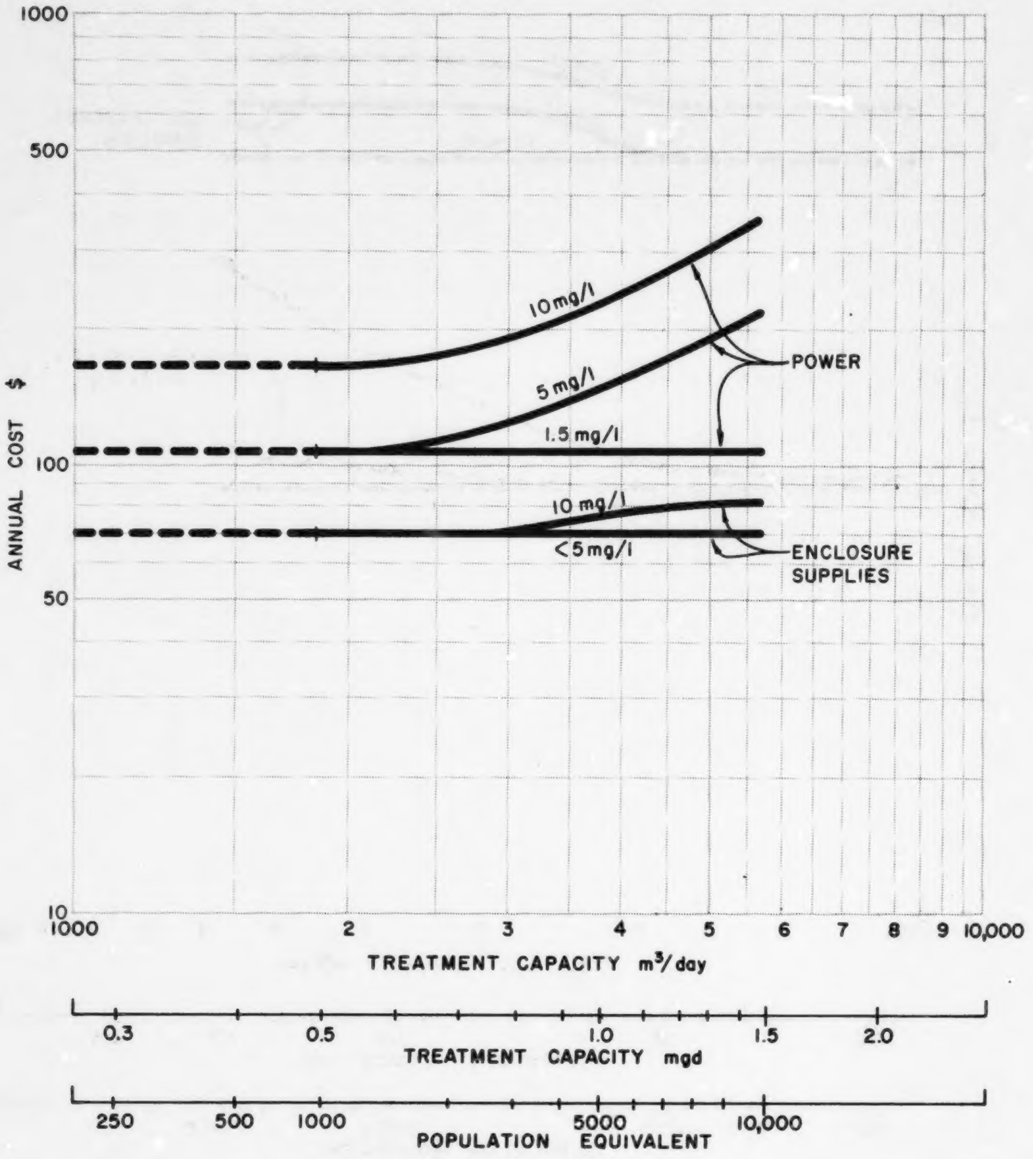


NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

CALCIUM HYPOCHLORITE
CHEMICAL FEED
UNIT PROCESS

OPERATION AND MAINTENANCE COST

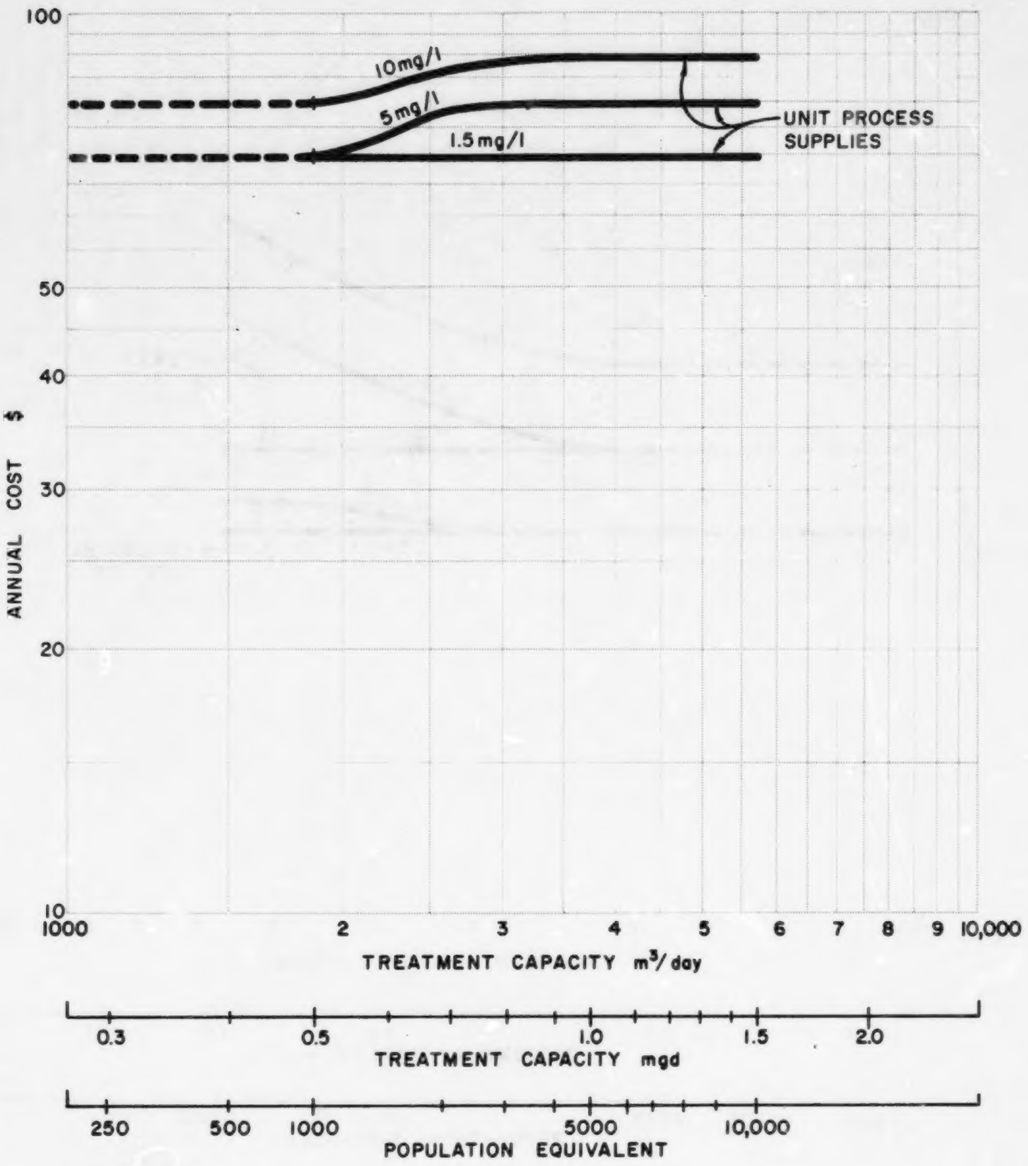
FIGURE 68



NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

CALCIUM HYPOCHLORITE
CHEMICAL FEED
POWER AND ENCLOSURE
OPERATION AND MAINTENANCE COST

FIGURE 69

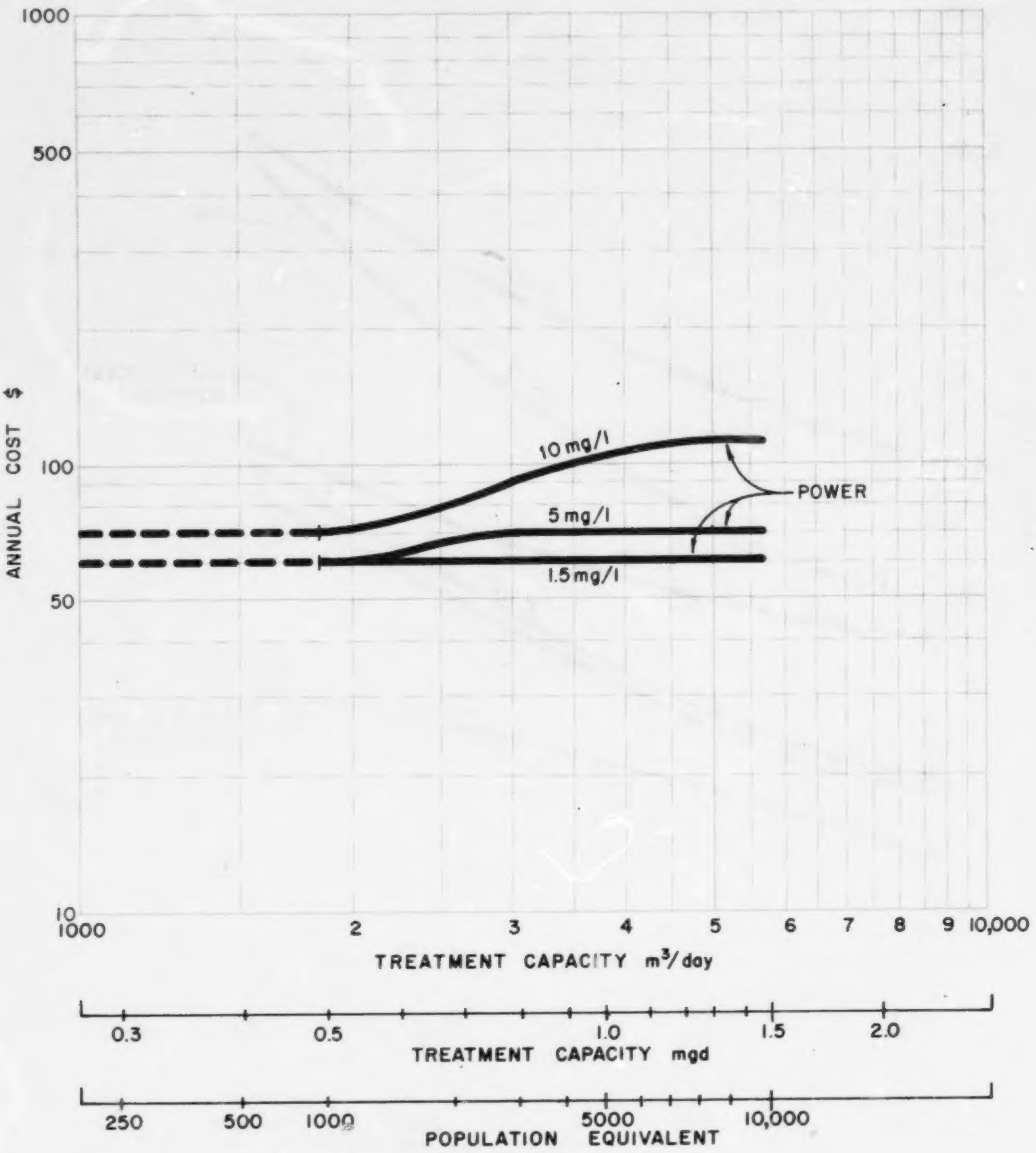


NOTES:

- ENCLOSURE SUPPLIES ANNUAL COST IS $70 FOR 10mg/l, 5mg/l & 1.5mg/l SYSTEMS.
- EXCLUDES LABOR. SEE PAGE VI-16.

SODIUM HYPOCHLORITE
CHEMICAL FEED
UNIT PROCESS AND ENCLOSURE
OPERATION AND MAINTENANCE COST

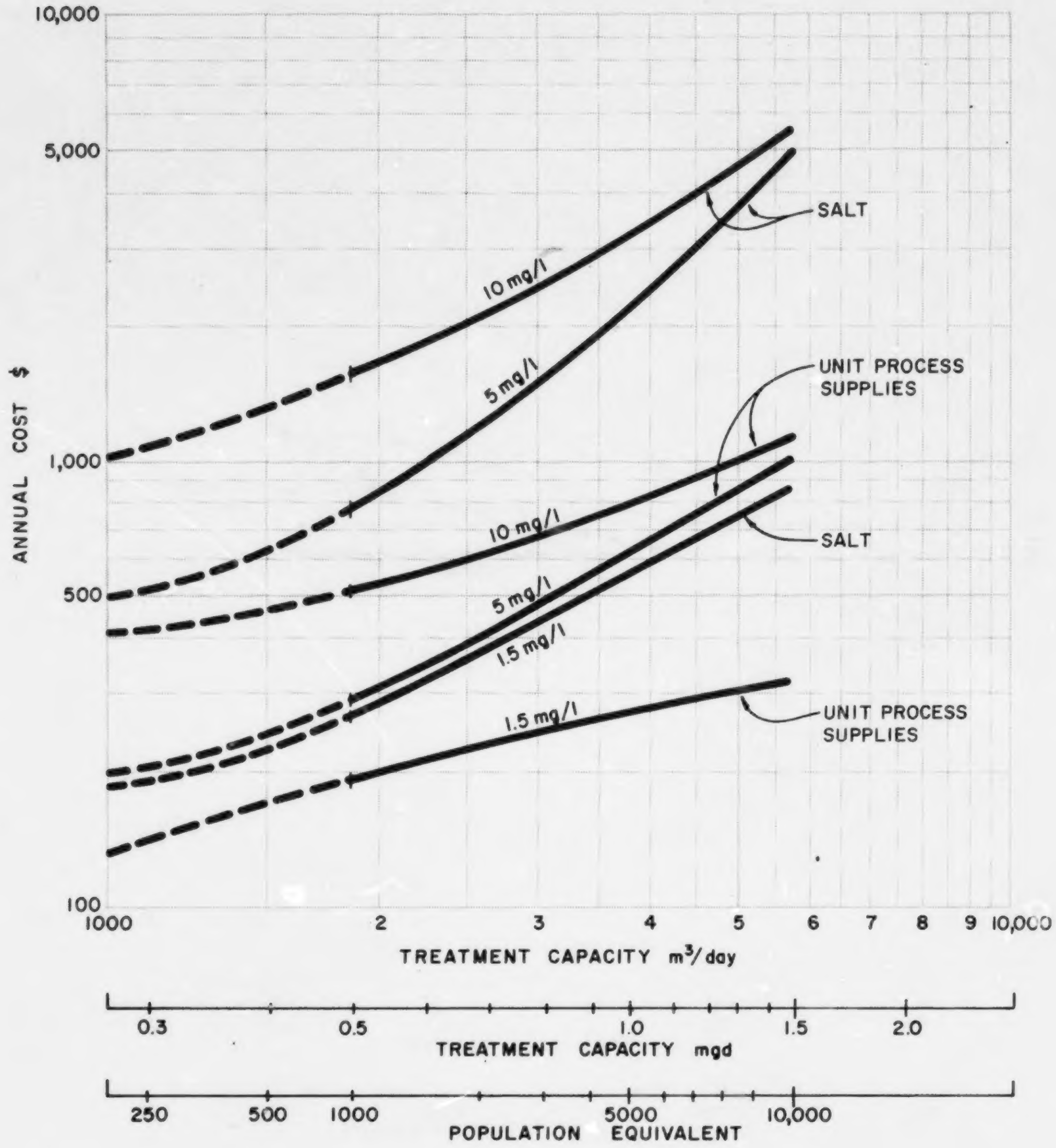
FIGURE 70



NOTE:
EXCLUDES LABOR. SEE
PAGE VI-16.

SODIUM HYPOCHLORITE
CHEMICAL FEED
POWER
OPERATION AND MAINTENANCE COST

FIGURE 71



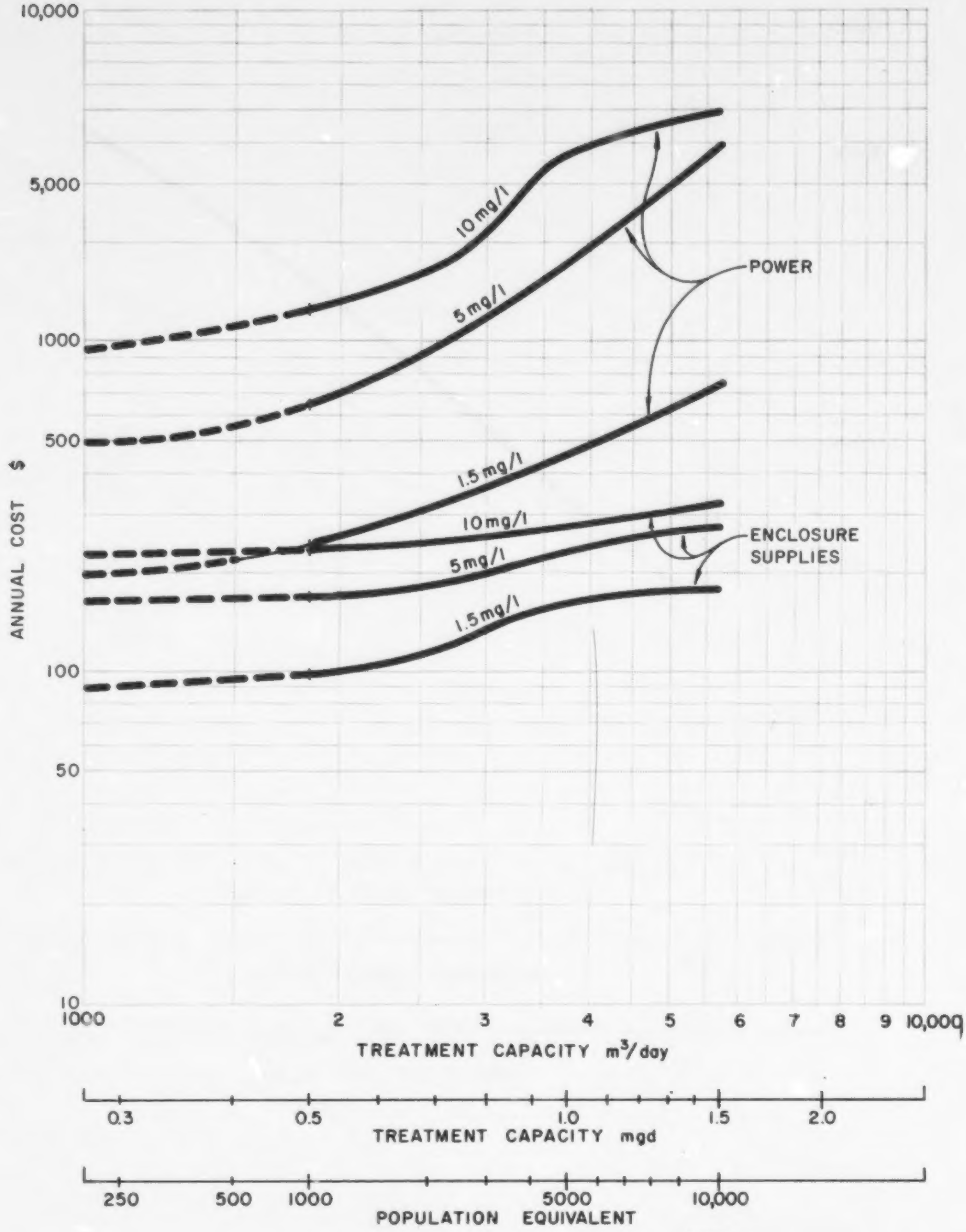
NOTE:

EXCLUDES LABOR. SEE PAGE VI - 16.

SODIUM HYPOCHLORITE ON-SITE GENERATION UNIT PROCESS

OPERATION AND MAINTENANCE COST

FIGURE 72



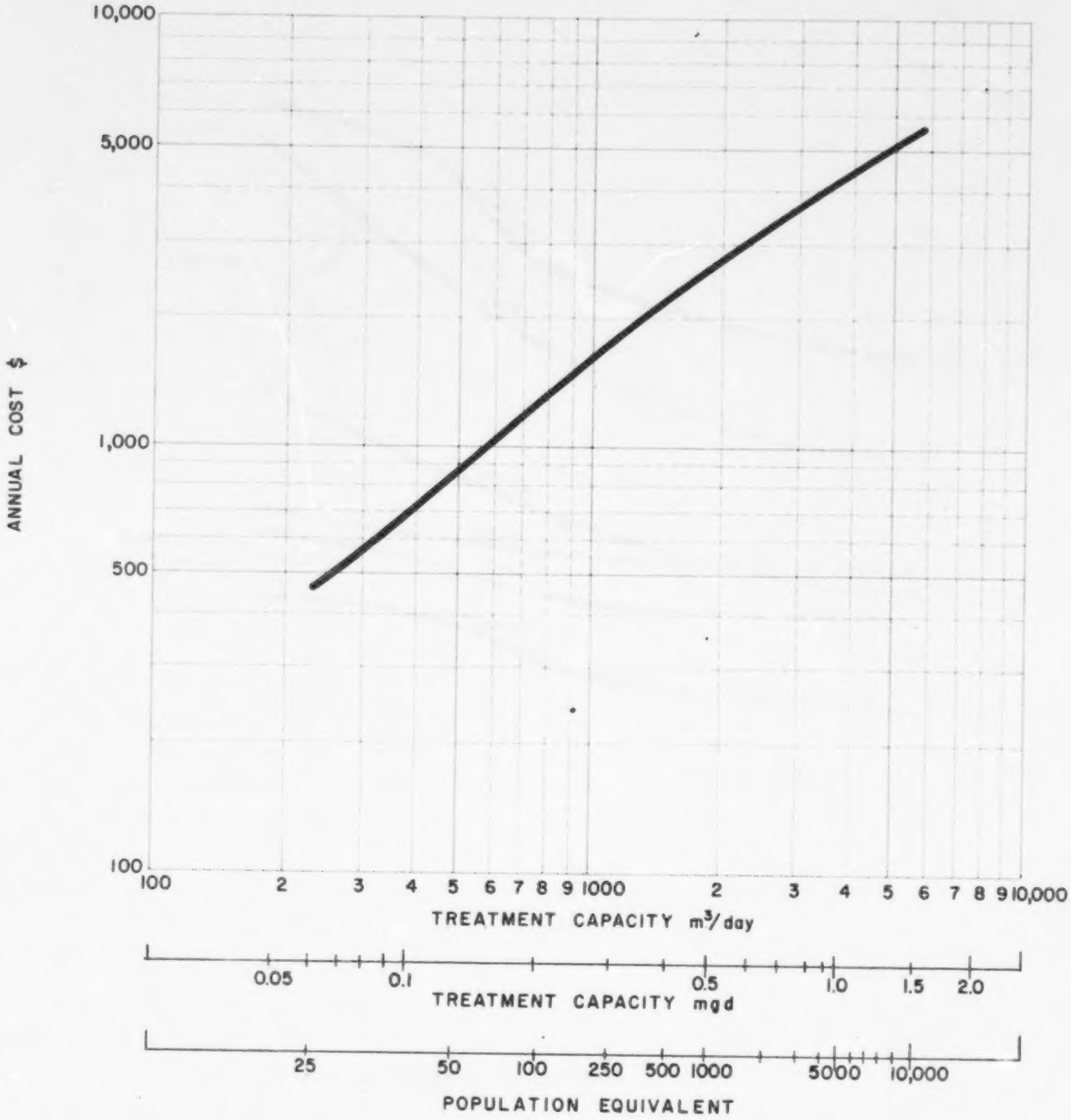
NOTE:

EXCLUDES LABOR. SEE PAGE VI - 16.

SODIUM HYPOCHLORITE
ON-SITE GENERATION
POWER AND ENCLOSURE

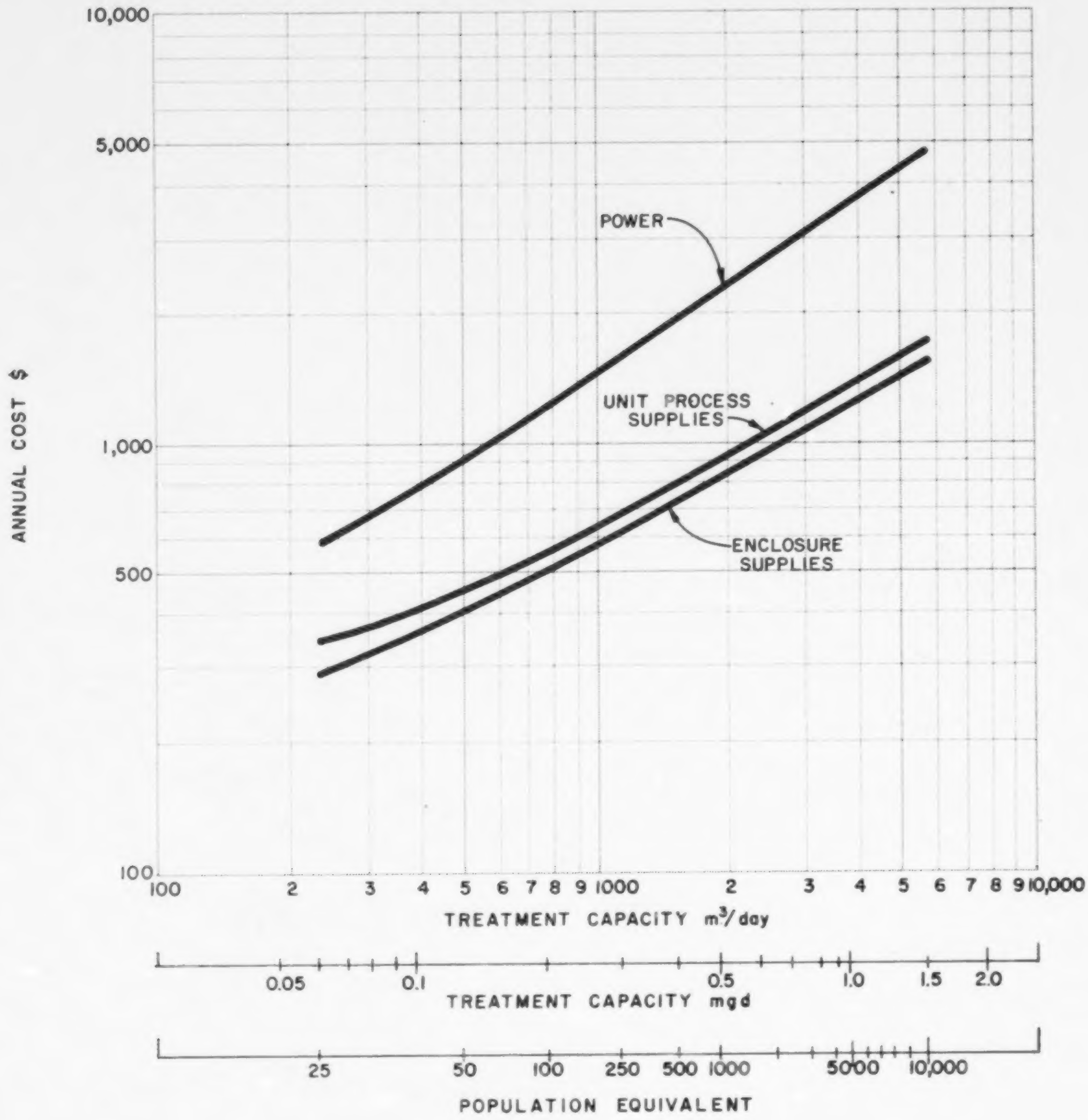
OPERATION AND MAINTENANCE COST

FIGURE 73



LAGOON
WASTE SOLIDS REMOVAL COST

FIGURE 74



NOTE:

EXCLUDES LABOR. SEE PAGE VI-16.

PACKAGE PLANT

OPERATION AND MAINTENANCE COST

FIGURE 75

APPENDIX A

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

141-A-1

federal register

WEDNESDAY, DECEMBER 24, 1975

THE NATIONAL ARCHIVES OF THE UNITED STATES · 1934

PART IV:

ENVIRONMENTAL PROTECTION AGENCY

WATER PROGRAMS

National Interim Primary Drinking Water Regulations

Title 40—Protection of Environment

CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

SUBCHAPTER D—WATER PROGRAMS

[FRL 464-7]

PART 141—NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

On March 14, 1975, the Environmental Protection Agency (EPA) proposed National Interim Primary Drinking Water Regulations pursuant to sections 1412, 1414, 1415, and 1450 of the Public Health Service Act ("the Act"), as amended by the Safe Drinking Water Act ("SDWA," Pub. L. 93-523), 40 FR 11990. EPA held public hearings on the proposed regulations in Boston, Chicago, San Francisco, and Washington during the month of April. Several thousand pages of comments on the proposed regulations were received and evaluated. In addition, the Agency has received comments and information on the proposed regulations from the National Drinking Water Advisory Council, the Secretary of Health, Education, and Welfare, and from numerous others during meetings with representatives of State agencies, public interest groups and others.

The regulations deal only with the basic legal requirements. Descriptive material will be provided in a guidance manual for use by public water systems and the States.

The purpose of this preamble to the final regulations is to summarize the most significant changes made in the proposed regulations as a result of comments received and the further consideration of available information. A more detailed discussion of the comments and of changes in the proposed regulations is attached as Appendix A.

WATER SYSTEMS COVERED

The Safe Drinking Water Act applies to each "public water system," which is defined in Section 1401(4) of the Act as "a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals." Privately owned as well as publicly owned systems are covered. Service "to the public" is interpreted by EPA to include factories and private housing developments. (See generally, House Report, pp. 16-17.)

The definition of "public water system" proposed in the Interim Primary Drinking Water Regulations sought to explain the meaning of the statutory reference to "regular" service. It was proposed to interpret this term as including service for as much as three months during the year. Because the proposed definition would have excluded many large campgrounds, lodges, and other public accommodations which serve large numbers of tourists but which are open for slightly less than three months each year, the definition in the final version covers systems serving an average of at least twenty-five individuals at least 60 days out of the year. The use of a minimum number of days rather than months also makes clear that a system may qualify as a public water system even if it is not open every day during a given month.

Once "public water system" has been defined, it is necessary to define the two major types of public water systems—those serving residents and those serving transients or intermittent users. The possible health effects of a contaminant in drinking water in many cases are quite different for a person drinking the water for a long period of time than for a person drinking the water only briefly or intermittently. Different regulatory considerations may, in some cases apply to systems which serve residents as opposed to systems which serve transients or intermittent users. Accordingly, § 141.2(e) makes clear that all "public water systems" fall within either the category of "community water systems" or the category of "non-community water systems." To make clear which regulatory requirements apply to which type of system, the category covered is specifically indicated throughout the regulations.

The proposed regulations defined a "community water system" as "a public water system which serves a population of which 70 percent or greater are residents." Reliance in the proposed definition on the percentage of water system users who are residents would result in treating some fairly large resort communities with many year-round residents as non-community systems. Therefore, the definition of "community water system" has been changed to cover any system which serves at least 15 service connections used by year-round residents or serves at least 25 year-round residents.

SMALL COMMUNITY WATER SYSTEMS

Many community water systems in the country are quite small. Since it is the intention of the Act to provide basically the same level of health protection to residents of small communities as to residents of large cities, and since a number of advanced water treatment techniques are made feasible only by economies of scale, the cost of compliance with the requirements of the Act may pose a serious problem for many small communities. The regulations seek to recognize the financial problems of small communities by requiring more realistic monitoring for systems serving fewer than 1,000 persons. Variances and exemptions authorized by the Act can also assist in dealing with economic problems of small community systems in appropriate cases, at least temporarily. EPA will provide technical assistance on effective treatment techniques which can be used by small systems.

These methods of dealing with the financial problems of some small community systems may not be sufficient in specific instances to make compliance with all applicable regulatory requirements feasible. EPA is commencing a study of potential problems faced by small community systems in meeting applicable requirements under the Act and these regulations, and, if necessary, will make additional adjustments in the Interim Primary Drinking Water Regulations prior to their effective date.

NON-COMMUNITY SYSTEMS

"Non-community systems" are basically those systems which serve transients. They include hotels, motels, restaurants, campgrounds, service stations, and other public accommodations which have their own water system and which have at least 15 service connections or serve water to a daily average of at least 25 persons. Some schools, factories and churches are also included in this category. It is conservatively estimated that there are over 200,000 non-community water systems in the country. However, it should be recognized that while their number is large, they normally are not the principal source of water for the people they serve.

The regulations as proposed would have applied all maximum contaminant levels to non-community systems as well as to community systems. This approach failed to take into account the fact that the proposed maximum contaminant levels for organic chemicals and most inorganic chemicals were based on the potential health effects of long-term exposure. Those levels are not necessary to protect transients or intermittent users. Therefore, the final regulations provide that maximum contaminant levels for organic chemicals, and for inorganic chemicals other than nitrates, are not applicable to non-community systems. An exception was made for nitrates because they can have an adverse health effect on susceptible infants in a short period of time.

Even without monitoring for organic chemicals or most inorganic chemicals, in the initial stages of implementation of the drinking water regulations, monitoring results from tens of thousands of non-community systems could overwhelm laboratory capabilities and other resources. This could delay effective implementation of the regulations with respect to the community systems which provide the water which Americans drink every day. To avoid this result, non-community systems will be given two years after the effective date of the regulations to commence monitoring. In the meantime, non-community systems which already monitor their water are encouraged to continue to do so, and the States are encouraged to take appropriate measures to test or require monitoring for non-community systems that serve large numbers of people.

Of course, non-community systems which pose a threat to health should be dealt with as quickly as possible. The maximum contaminant levels applicable to non-community water systems therefore will take effect 18 months after promulgation, at the same time as levels applicable to community systems. Inspection and enforcement authority will apply to non-community systems at the same time as to community systems.

SANITARY SURVEYS

EPA encourages the States to conduct sanitary surveys on a systematic basis.

These on-site inspections of water systems are more effective in assuring safe water to the public than individual tests taken in the absence of sanitary surveys. The regulations provide that monitoring frequencies for coliform bacteria can be changed by the entity with primary enforcement responsibility for an individual non-community system, and in certain circumstances for an individual community system, based on the results of a sanitary survey.

Maximum Contaminant Levels

Numerous comments were received by EPA on the substances selected for the establishment of maximum contaminant levels and on the levels chosen. Congress anticipated that the initial Interim Primary Drinking Water Regulations would be based on the Public Health Service Standards of 1962, and this Congressional intent has been followed. Comments received on the various levels did not contain new data sufficient to require the establishment of levels different from those contained in the Public Health Service Standards.

Water Consumption

The maximum contaminant levels are based, directly or indirectly, on an assumed consumption of two liters of water per day. The same assumption was used in the 1962 Standards. This assumption has been challenged because of instances where much higher water consumption rates occur. EPA's justification for using the two-liter figure is that it already represents an above average water or water-based fluid intake. Moreover, while the factor of safety may be somewhat reduced when greater quantities of water are ingested, the maximum contaminant levels based on the two-liter figure provide substantial protection to virtually all consumers. If, as has been suggested, a water consumption rate of eight liters per day is used as the basis for maximum contaminant level, all of the proposed MCL's would have to be divided by four, greatly increasing the monitoring difficulties, and in some cases challenging the sensitivity of accepted analytical procedures. It could be expected, in such a case, that the maximum contaminant levels would be exceeded to a significant degree, and that specialized treatment techniques would be required to order that the contaminant levels would be reduced. The economic impact of a move in this direction would be enormous. It is not technically or economically feasible to base maximum contaminant levels on unusually high consumption rates.

Safety Factors

A question was raised about the fact that different safety factors are contained in various maximum contaminant levels. The levels are not intended to have a uniform safety factor, at least partly because the knowledge of and the nature of the health risks of the various contaminants vary widely. The levels set are the result of experience, evaluation of the available data, and professional judgment. They have withstood the test of time and of professional review. They are being subjected to further review by the National Academy of Sciences in connection with development of data for the Revised Primary Drinking Water Regulations.

MCL's Based on Temperature

A question was also raised as to whether ranges of maximum contaminant levels should be established on the basis of the climate in the area served by the public water system, as was done with fluoride. EPA believes that the use of a temperature scale for fluoride is more appropriate than for other chemicals because of the studies available on the fluoride-temperature relationship and because there is a small margin with fluoride between beneficial levels and levels that cause adverse health effects.

MCL's Deleted

Three proposed maximum contaminant levels have been eliminated in the final regulations because they are not justified by the available data. One of these is carbon chloroform extract (CCE), which is discussed separately below. The others are the proposed levels for the standard bacterial plate count and cyanide. In the case of the plate count, it is believed that the coliform limits contained in the regulations, combined with the turbidity maximum contaminant level, adequately deal with bacterial contamination. However, EPA continues to believe that the standard plate count is a valid indicator of bacteriological quality of drinking water, and recommends that it be used in appropriate cases in conjunction with the coliform tests as an operational tool.

The proposed maximum contaminant level for cyanide was eliminated because the possibility of cyanide contamination can be effectively addressed only by the use of emergency action, such as under Section 1431 of the Act. EPA's 1969 Community Water Supply Study did not reveal a single instance in which cyanide was present in a water system at a level greater than one-thousandth of the level at which cyanide is toxic to humans.

Available data indicate that cyanide will be present in water systems at toxic levels only in the event of an accident, such as a spill from a barge collision. Maximum contaminant levels are not the appropriate vehicle for dealing with such rare, accidental contamination.

Heptachor, heptachlor epoxide and chlordane have also been removed from the list of maximum contaminant levels at least temporarily in view of the pending cancellation and suspension proceedings under the Federal Insecticide, Fungicide and Rodenticide Act involving those pesticides. When the results of these proceedings are available, EPA will again consider whether maximum contaminant levels should be established for those three pesticides.

Sodium and Sulfates

A number of comments were received on the potential health effects of sodium and sulfates. The National Drinking Water Advisory Council has recommended that consideration be given to the monitoring of these constituents, but has not recommended the adoption of maximum contaminant levels because available data do not support the adoption of any specific levels. EPA has requested the National Academy of Sciences to include sodium and sulfates among the contaminants to be studied by NAS, and to include information on the health effects of sodium and sulfates in the report to be made by NAS in December 1976.

Since a number of persons suffer from diseases which are influenced by dietary sodium intake and since there are others who wish to restrict their sodium intake, it is desirable that the sodium content of drinking water be known. Those affected can, by knowing the sodium concentration in their drinking water, make adjustments to their diets or, in extreme cases, seek alternative sources of water to be used for drinking and food preparation. It is recommended that the States institute programs for regular monitoring of the sodium content of drinking water served to the public, and for informing physicians and consumers of the sodium concentration in drinking water.

A relatively high concentration of sulfate in drinking water has little or no known laxative effect on regular users of the water, but transcients using such water sometimes experience a laxative effect. It is recommended that the States institute monitoring programs for sulfates, and that transients be notified if the sulfate content of the water is high. Such notification should include an assessment of the possible physiological effects of consumption of the water.

PCB's and Asbestos

An interagency comment expressed concern for asbestos and PCB's in the environment and noted the need for at least a monitoring requirement, if not for MCL's, for these contaminants. EPA is also concerned, but for the moment lacks sufficient evidence regarding analytical methods, health effects, or occurrence in the environment to establish MCL's. The Agency is conducting research and cooperating in research projects to develop criteria for establishing needed limits as quickly as possible. A monitoring study on a number of organic chemical contaminants, including PCB's, for which MCL's are not being established at this time, will be contained in an organic chemical monitoring regulation that is being promulgated with these regulations. Regarding asbestos, HEW and EPA are sponsoring a number of studies this year at an approximate cost of $16 million to establish health effects, anayltical methods and occurrence.

Point of Measurement

Other comments on maximum contaminant levels focused on the proposed requirement that such levels be tested at the consumer's tap. Concern was expressed over the inability of the public water system to control potential sources of contaminants which are under the control of the consumer.

The promulgated definition of "maximum contaminant level," § 141.2(d), retains the requirement that the maximum contaminant level be measured at the tap except in the case of turbidity, which should be measured at the point of entry to the distribution system. However, the definition has been expanded to make clear that contaminants added to the water by circumstances under the control of the consumer are not the responsibility of the supplier of water, unless the contaminants result from corrosion of piping and plumbing resulting from the quality of the water supplied. It should be noted, however, that this requirement should not be interpreted as to discourage local, aggressive cross connection control measures.

COLIFORM BACTERIA MCL'S

The promulgated MCL's for coliform bacteria are basically the 1962 Public Health Service Standards, with minor refinements and clarifications. However, further changes may be desirable. For example, the MCL's for the membrane filter analytical method do not resolve the question of how many coliform bacteria are assumed to be present in a single highly contaminated sample. Some laboratories assume an upper limit of 50, while others seek to continue to count individual bacteria to a level of 100 or even higher in a single sample. The upper limit assumed will affect the monthly average which is calculated to determine compliance with the MCL's.

Another question relating to the coliform bacteria MCL's is the matter of possible spurious positive samples. As the regulations are written, all routine samples taken to determine compliance with the MCL's must be counted, regardless of the results of analysis of any check samples that may be taken. The reason for this is that bacterial contamination is often intermittent or transient, and as a result negative check samples taken a day or more after a positive sample cannot demonstrate that the positive result was in error. It may be possible, however, to prescribe a means of dealing with spurious positive results without compromising the integrity of the MCL's.

A third question concerning the MCL's for coliform bacteria is the relationship of monthly averages of coliform bacteria levels to monthly percentages of positive samples. For example, the monthly average MCL for the membrane filter method is violated if the monthly average exceeds one coliform bacterium per sample. However, for purposes of determining whether the monthly-percentage-of-positive-samples MCL is violated, a sample is counted as positive only if it contains more than four coliform bacteria. Thus, it is possible, particularly when a relatively small number of samples is taken, for a system to fail the monthly average MCL even when no single sample taken during the month is out of compliance with the limit.

These and other questions concerning the coliform bacteria MCL's will be reviewed further by EPA. If review indicates that changes in the MCL's are desirable, those changes will be made as soon as possible but within 6 months, in time to take effect at the same time as the initial Interim Primary Drinking Water Regulations.

ORGANIC CHEMICALS

The proposed maximum contaminant levels for organic pesticides, other than the three which are the subject of cancellation and suspension proceedings, have been retained. It is anticipated that additional organic pesticides will be added to the regulations if surveys of pesticides in drinking water being conducted by EPA indicate that this is needed.

The proposed regulations also contained a maximum contaminant level for organic chemicals obtained by the carbon chloroform extract (CCE) method. It was anticipated by Congress that organic chemicals would be dealt with primarily in the Revised Primary Drinking Water Regulations because of the paucity of accurate data on the health effects of various organic chemicals, the large number of such chemicals, uncertainities over appropriate treatment techniques, and the need for additional information on the incidence of specific organic chemicals in drinking water supplies. EPA thought that the CCE standard might provide an appropriate means of dealing with organic chemicals as a class pending action on the Revised Primary Regulations.

The CCE standard was originally developed as a test for undesirable tastes and odors in drinking water. As concern developed over the health effects of organic chemicals, the possibility of using CCE as a health standard rather than an esthetic standard was considered.

As pointed out by numerous comments, CCE has many failings as an indicator of health effects of organic chemicals. To begin with, the test obtains information on only a fraction of the total amount of organic chemicals in the water sampled. Furthermore, there is serious question as to the reliability of CCE in identifying those organic chemicals which are most suspected of adverse health effects. In addition, there are no existing data on which a specific level for CCE can be established on a rational basis. To establish a maximum contaminant level under these circumstances would almost certainly do more harm than good. It could give a false sense of security to persons served by systems which are within the established level and a false sense of alarm to persons served by systems which exceed the level. It also would divert resources from efforts to find more effective ways of dealing with the organic chemicals problem.

EPA believes that the intelligent approach to the organic chemicals question is to move ahead as rapidly as possible along two fronts. First, EPA is adopting simultaneously with these regulations a Subpart E of Part 141, containing requirements for organic chemical monitoring pursuant to Sections 1445 and 1450 of the Act.

The regulations require that designated public water systems collect samples of raw and treated water for submission to EPA for organics analysis. EPA will analyze the samples for a number of broad organic parameters, including carbon chloroform extract (CCE), volatile and non-volatile total organic carbon (VTOC and NVTOC), total organic chlorine (TOCl), ultraviolet absorbancy, and fluorescence. In addition, monitoring will be required for probably 21 specific organic compounds. Selection of the specific compounds has been based on the occurrence or likelihood of occurrence in treated water, toxicity data and availability of practical analytical methods. Laboratory analyses will be used to evaluate the extent and nature of organic chemical contamination of drinking water, to evaluate the validity of the general organic parameters as surrogates for measures of harmful organic chemicals, and to determine whether there is an adequate basis for establishing maximum contaminant levels for specific organics or groups of organics.

Second, EPA is embarking on an intensive research program to find answers to the following four questions:

1. What are the effects of commonly occurring organic compounds on human health?

2. What analytical procedures should be used to monitor finished drinking water to assure that any Primary Drinking Water Regulations dealing with organics are met?

3. Because some of these organic compounds are formed during water treatment, what changes in treatment practices are required to minimize the formation of these compounds in treated water?

4. What treatment technology must be applied to reduce contaminant levels to concentrations that may be specified in the Primary Drinking Water Regulations?

This research will involve health-effects and epidemiological studies, investigations of analytical methodology, and pilot plant and field studies of organic removal unit processes. Some phases of the research are to be completed by the end of this year, while much of the remainder are to be completed within the next calendar year.

As soon as sufficient information is derived from the monitoring program and related research, the Interim Primary Drinking Water Regulations will be amended so that the organic chemicals problem can be dealt with without delay. The monitoring process will be completed within 1 year.

During the interim period, while satisfactory MCL's for organic contamination in drinking water are being developed, EPA will act in specific cases where appropriate to deal with organic contamination. If the EPA monitoring program reveals serious specific cases of contamination, EPA will work with State and local authorities to identify the source and nature of the problem and to take remedial action. EPA will also aid the States in identifying additional community water supplies that require analysis.

PUBLIC NOTICE

The public notice requirements proposed in § 141.32 did not distinguish between community and non-community public water systems. They would have required that public notice of non-compliance with applicable regulations be made by newspaper, in water bills, and by other media for all public water systems. These requirements are inappropriate and ineffective in the case of most non-community water systems. Those systems principally serve transients who do not receive water bills from the system and who probably are not exposed significantly to the local media. A more effective approach would be to require notice that can inform the transient before he drinks the system's water, and thereby both warn the transient and provide an incentive to the supplier of water to remedy the violation. Accordingly, Section 141.32 as adopted provides that in the case of non-community systems, the entity with primary enforcement responsibility shall require that notice be given in a form and manner that will insure that the public using the public water system is adequately informed.

The proposed public notice requirements also failed to distinguish between different types of violations of the Interim Primary Drinking Water Regulations. Since the urgency and importance of a notice varies according to the nature of the violation involved, § 141.32 as promulgated seeks to match the type of notice required with the type of violation involved. Written notice accompanying a water bill or other direct notice by mail is required for all violations of the regulations, including violations of monitoring requirements, and for the grant of a variance or exemption. In addition, notice by newspaper and notification to radio and television stations is required whenever a maximum contaminant level is exceeded, or when the entity with primary enforcement responsibility requires such broader notice.

QUALITY CONTROL AND TESTING PROCEDURES

Section 1401(1) of the Act defines "primary drinking water regulation" to include "quality control and testing procedures." The promulgated regulations include testing requirements for each maximum contaminant level, including check samples and special samples in appropriate cases. The regulations also specify the procedures to be followed in analyzing samples for each of the maximum contaminant levels. These procedures will be updated from time to time as advances are made in analytical methods. For example, references to "Standard Methods for the Examination of Water and Wastewater" are to the current, 13th, edition, but these references will be changed to cite the 14th edition when it is available in the near future.

A key element of quality control for public water systems is accurate laboratory analysis. Section 141.28 of the regulations provides that analyses conducted for the purpose of determining compliance with maximum contaminant levels must be conducted by a laboratory approved by the entity with primary enforcement responsibility. EPA will develop as soon as possible, in cooperation with the States and other interested parties, criteria and procedures for laboratory certification. A State with primary enforcement responsibility will have a laboratory certified by EPA pursuant to the prescribed criteria and procedures, and in turn will certify laboratories within the State.

Record-keeping requirements and reports to the State also will assist in quality control efforts.

RECORD-KEEPING

Adequate record-keeping is necessary for the proper operation and administration of a public water system. It is also important for providing information to the public, providing appropriate data for inspection and enforcement activities and providing information on which future regulations can be based. Accordingly, a new § 141.33 has been added to the regulations to require that each public water system maintain records of sample analyses and of actions to correct violations of the Primary Drinking Water Regulations.

ECONOMIC AND COST ANALYSIS

A comprehensive economics study has been made of the Interim Primary Drinking Water Regulations. This study estimates the costs of the regulations, evaluates the potential economic impact, and considers possible material and labor shortages. The results of this analysis are summarized here.

Total investment costs to community water systems to achieve compliance with these regulations are estimated to be between $1,050 and $1,765 million. It is estimated that non-community systems will invest an additional $24 million. The range of the estimate is due to uncertainty as to the design flow that will be used in installing treatment facilities. Systems not in compliance will have to consider sizing their new components to reflect average daily flow conditions, or maximum daily flow conditions in cases where system storage is not adequate.

This investment will be spread over several years. Investor-owned systems will bear about one-fourth of these costs, and publicly-owned systems the remainder. It is not anticipated that systems will have difficulty financing these capital requirements.

In annual terms, national costs are expected to be within the following ranges:

	In millions
Capital costs	$146–247
Operations and maintenance	263–263
Monitoring (routine only)	17– 35
Total	$426–545

Although these aggregate figures are large, most water consumers will not be significantly affected. For those users in systems serving 10,000 persons or more, the average annual treatment cost per capita may increase from less than $1.00 for systems requiring disinfection and lead control, to between $15 to $35 for control of turbidity and heavy metal removal. For systems serving less than 100 persons, the average annual per capita costs of disinfection, lead control and fluoride/arsenic removal are estimated to be between $2.10 and $11.80. However, if turbidity control or heavy metal removal were required in a system of this size then costs are expected to range from $52 to $237 per year per capita. EPA is aware of the serious potential economic impact on users in these small systems. However, the legislative history specifies that the regulations should be based on costs that can be reasonably afforded by large metropolitan or regional systems. Further economic evaluation of these systems is being conducted, and realistic options for these small systems are being reviewed. Options that will be under consideration include less costly treatment technologies; formation of regional systems; and use of alternative water sources. Industrial and commercial users, whether providing their own water or using public systems, are not expected to be significantly affected by these regulations.

Possible constraints to the implementation of the interim primary regulations were examined. Although there will be an increase in demand for chemicals, manpower, laboratories, and construction of treatment facilities, it is not anticipated that any of these factors will be a serious obstacle to implementation of these regulations over a reasonable time frame.

For the reasons given above, Chapter 40 of the Code of Federal Regulations is hereby amended by the addition of the following new Part 141. These regulations will take effect 18 months after promulgation.

(It is hereby certified that the economic and inflationary impacts of these regulations have been carefully evaluated in accordance with Executive Order 11821)

Dated: December 10, 1975.

RUSSELL E. TRAIN,
Administrator.

Subpart A—General

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141.1 Applicability.
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Subpart D—Reporting, Public Notification, and Record-keeping

141.31 Reporting requirements.
141.32 Public notification of variances, exemptions, and non-compliance with regulations.
141.33 Record maintenance.

AUTHORITY: Secs. 1412, 1414, 1445, and 1450 of the Public Health Service Act, 88 Stat. 1660 (42 U.S.C. 300g-1, 300g-3, 300j-4, and 300j-9).

Subpart A—General

§ 141.1 Applicability.

This part establishes primary drinking water regulations pursuant to section 1412 of the Public Health Service Act, as amended by the Safe Drinking Water Act (Pub. L. 93-523); and related regulations applicable to public water systems.

§ 141.2 Definitions.

As used in this part, the term:

(a) "Act" means the Public Health Service Act, as amended by the Safe Drinking Water Act, Pub. L. 93-523.

(b) "Contaminant" means any physical, chemical, biological, or radiological substance or matter in water.

(c) "Maximum contaminant level" means the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

(d) "Person" means an individual, corporation, company, association, partnership, State, municipality, or Federal agency.

(e) "Public water system" means a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes (1) any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system, and (2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. A public water system is either a "community water system" or a "non-community water system."

(i) "Community water system" means a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

(ii) "Non-community water system" means a public water system that is not a community water system.

(f) "Sanitary survey" means an on-site review of the water source, facilities, equipment, operation and maintenance of a public water system for the purpose of evaluating the adequacy of such source, facilities, equipment, operation and maintenance for producing and distributing safe drinking water.

(g) "Standard sample" means the aliquot of finished drinking water that is examined for the presence of coliform bacteria.

(h) "State" means the agency of the State government which has jurisdiction over public water systems. During any period when a State does not have primary enforcement responsibility pursuant to Section 1413 of the Act, the term "State" means the Regional Administrator, U.S. Environmental Protection Agency.

(i) "Supplier of water" means any person who owns or operates a public water system.

§ 141.3 Coverage.

This part shall apply to each public water system, unless the public water system meets all of the following conditions:

(a) Consists only of distribution and storage facilities (and does not have any collection and treatment facilities);

(b) Obtains all of its water from, but is not owned or operated by, a public water system to which such regulations apply:

(c) Does not sell water to any person; and

(d) Is not a carrier which conveys passengers in interstate commerce.

§ 141.4 Variances and exemptions.

Variances or exemptions from certain provisions of these regulations may be granted pursuant to Sections 1415 and 1416 of the Act by the entity with primary enforcement responsibility. Provisions under Part 142, *National Interim Primary Drinking Water Regulations Implementation*—subpart E (Variances) and subpart F (Exemptions)—apply where EPA has primary enforcement responsibility.

§ 141.5 Siting requirements.

Before a person may enter into a financial commitment for or initiate construction of a new public water system or increase the capacity of an existing public water system, he shall notify the State and, to the extent practicable, avoid locating part or all of the new or expanded facility at a site which:

(a) Is subject to a significant risk from earthquakes, floods, fires or other disasters which could cause a breakdown of the public water system or a portion thereof; or

(b) Except for intake structures, is within the floodplain of a 100-year flood or is lower than any recorded high tide where appropriate records exist.

The U.S. Environmental Protection Agency will not seek to override land use decisions affecting public water systems siting which are made at the State or local government levels.

§ 141.6 Effective date.

The regulations set forth in this part shall take effect 18 months after the date of promulgation.

Subpart B—Maximum Contaminant Levels

§ 141.11 Maximum contaminant levels for inorganic chemicals.

(a) The maximum contaminant level for nitrate is applicable to both community water systems and non-community water systems. The levels for the other inorganic chemicals apply only to community water systems. Compliance with maximum contaminant levels for inorganic chemicals is calculated pursuant to § 141.23.

(b) The following are the maximum contaminant levels for inorganic chemicals other than fluoride:

Contaminant	*Level, milligrams per liter*
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

(c) When the annual average of the maximum daily air temperatures for the location in which the community water system is situated is the following, the maximum contaminant levels for fluoride are:

Temperature Degrees Fahrenheit	Degrees Celsius	Level, milligrams per liter
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

§ 141.12 Maximum contaminant levels for organic chemicals.

The following are the maximum contaminant levels for organic chemicals. They apply only to community water systems. Compliance with maximum contaminant levels for organic chemicals is calculated pursuant to § 141.24.

	Level, milligrams per liter
(a) Chlorinated hydrocarbons:	
Endrin (1,2,3,4,10, 10-hexachloro-6,7-epoxy-1,4, 4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8 - dimethano naphthalene).	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer).	0.004
Methoxychlor (1,1,1-Trichloro-2, 2 - bis [p-methoxyphenyl] ethane).	0.1
Toxaphene ($C_{10}H_{10}Cl_8$-Technical chlorinated camphene, 67-69 percent chlorine).	0.005

(b) Chlorophenoxys:	
2,4-D, (2,4-Dichlorophenoxyacetic acid).	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid).	0.01

§ 141.13 Maximum contaminant levels for turbidity.

The maximum contaminant levels for turbidity are applicable to both community water systems and non-community water systems using surface water sources in whole or in part. The maximum contaminant levels for turbidity in drinking water, measured at a representative entry point(s) to the distribution system, are:

(a) One turbidity unit (TU), as determined by a monthly average pursuant to § 141.22, except that five or fewer turbidity units may be allowed if the supplier of water can demonstrate to the State that the higher turbidity does not do any of the following:

(1) Interfere with disinfection;

(2) Prevent maintenance of an effective disinfectant agent throughout the distribution system; or

(3) Interfere with microbiological determinations.

(b) Five turbidity units based on an average for two consecutive days pursuant to § 141.22.

§ 141.14 Maximum microbiological contaminant levels.

The maximum contaminant levels for coliform bacteria, applicable to community water systems and non-community water systems, are as follows:

(a) When the membrane filter technique pursuant to § 141.21(a) is used, the number of coliform bacteria shall not exceed any of the following:

(1) One per 100 milliliters as the arithmetic mean of all samples examined per month pursuant to § 141.21 (b) or (c);

(2) Four per 100 milliliters in more than one sample when less than 20 are examined per month; or

(3) Four per 100 milliliters in more than five percent of the samples when 20 or more are examined per month.

(b)(1) When the fermentation tube method and 10 milliliter standard portions pursuant to § 141.21(a) are used, coliform bacteria shall not be present in any of the following:

(i) more than 10 percent of the portions in any month pursuant to § 141.21 (b) or (c);

(ii) three or more portions in more than one sample when less than 20 samples are examined per month; or

(iii) three or more portions in more than five percent of the samples when 20 or more samples are examined per month.

(2) When the fermentation tube method and 100 milliliter standard portions pursuant to § 141.21(a) are used, coliform bacteria shall not be present in any of the following:

(i) more than 60 percent of the portions in any month pursuant to § 141.21 (b) or (c);

(ii) five portions in more than one sample when less than five samples are examined per month; or

(iii) five portions in more than 20 percent of the samples when five or more samples are examined per month.

(c) For community or non-community systems that are required to sample at a rate of less than 4 per month, compliance with paragraphs (a), (b)(1), or (b)(2) of this section shall be based upon sampling during a 3 month period, except that, at the discretion of the State, compliance may be based upon sampling during a one-month period.

Subpart C—Monitoring and Analytical Requirements

§ 141.21 Microbiological contaminant sampling and analytical requirements.

(a) Suppliers of water for community water systems and non-community water systems shall analyze for coliform bacteria for the purpose of determining compliance with § 141.14. Analyses shall be conducted in accordance with the analytical recommendations set forth in "Standard Methods for the Examination of Water and Wastewater," American Public Health Association, 13th Edition, pp. 662–688, except that a standard sample size shall be employed. The standard sample used in the membrane filter procedure shall be 100 milliliters. The standard sample used in the 5 tube most probable number (MPN) procedure (fermentation tube method) shall be 5 times the standard portion. The standard portion is either 10 milliliters or 100 milliliters as described in § 141.14 (b) and (c). The samples shall be taken at points which are representative of the conditions within the distribution system.

(b) The supplier of water for a community water system shall take coliform density samples at regular time intervals, and in number proportionate to the population served by the system. In no event shall the frequency be less than as set forth below:

Population served:	*Minimum number of samples per month*
25 to 1,000	1
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 9,400	10
9,401 to 10,300	11
10,301 to 11,100	12
11,101 to 12,000	13
12,001 to 12,900	14
12,901 to 13,700	15
13,701 to 14,600	16
14,601 to 15,500	17
15,501 to 16,300	18
16,301 to 17,200	19
17,201 to 18,100	20
18,101 to 18,900	21
18,901 to 19,800	22
19,801 to 20,700	23
20,701 to 21,500	24
21,501 to 22,300	25
22,301 to 23,200	26
23,201 to 24,000	27
24,001 to 24,900	28
24,901 to 25,000	29
25,001 to 28,000	30
28,001 to 33,000	35
33,001 to 37,000	40
37,001 to 41,000	45
41,001 to 46,000	50
46,001 to 50,000	55
50,001 to 54,000	60
54,001 to 59,000	65
59,001 to 64,000	70
64,001 to 70,000	75
70,001 to 76,000	80
76,001 to 83,000	85
83,001 to 90,000	90
90,001 to 96,000	95
96,001 to 111,000	100
111,001 to 130,000	110
130,001 to 160,000	120
160,001 to 190,000	130
190,001 to 220,000	140
220,001 to 250,000	150
250,001 to 290,000	160
290,001 to 320,000	170
320,001 to 360,000	180
360,001 to 410,000	190
410,001 to 450,000	200
450,001 to 500,000	210
500,001 to 550,000	220
550,001 to 600,000	230
600,001 to 660,000	240
660,001 to 720,000	250
720,001 to 780,000	260
780,001 to 840,000	270
840,001 to 910,000	280
910,001 to 970,000	290
970,001 to 1,050,000	300
1,050,001 to 1,140,000	310
1,140,001 to 1,230,000	320
1,230,001 to 1,320,000	330
1,320,001 to 1,420,000	340
1,420,001 to 1,520,000	350
1,520,001 to 1,630,000	360
1,630,001 to 1,730,000	370
1,730,001 to 1,850,000	380
1,850,001 to 1,970,000	390
1,970,001 to 2,060,000	400
2,060,001 to 2,270,000	410
2,270,001 to 2,510,000	420
2,510,001 to 2,750,000	430
2,750,001 to 3,020,000	440
3,020,001 to 3,320,000	450
3,320,001 to 3,620,000	460
3,620,001 to 3,960,000	470
3,960,001 to 4,310,000	480
4,310,001 to 4,690,000	490
4,690,001 or more	500

Based on a history of no coliform bacterial contamination and on a sanitary survey by the State showing the water system to be supplied solely by a protected ground water source and free of sanitary defects, a community water system serving 25 to 1,000 persons, with written permission from the State, may reduce this sampling frequency except that in no case shall it be reduced to less than one per quarter.

(c) The supplier of water for a non-community water system shall sample for coliform bacteria in each calendar quarter during which the system provides water to the public. Such sampling shall begin within two years after the effective date of this part. If the State, on the basis of a sanitary survey, determines that some other frequency is more appropriate, that frequency shall be the frequency required under these regulations. Such frequency shall be confirmed or changed on the basis of subsequent surveys.

(d)(1) When the coliform bacteria in a single sample exceed four per 100 milliliters (§ 141.14(a)), at least two consecutive daily check samples shall be collected and examined from the same sampling point. Additional check samples shall be collected daily, or at a frequency established by the State, until the results obtained from at least two consecutive check samples show less than one coliform bacterium per 100 milliliters.

(2) When coliform bacteria occur in three or more 10 ml portions of a single sample (§ 141.14(b)(1)), at least two consecutive daily check samples shall be collected and examined from the same sampling point. Additional check samples shall be collected daily, or at a frequency established by the State, until the results obtained from at least two consecutive check samples show no positive tubes.

(3) When coliform bacteria occur in all five of the 100 ml portions of a single sample (§ 141.14(b)(2)), at least two daily check samples shall be collected and examined from the same sampling point. Additional check samples shall be collected daily, or at a frequency established by the State, until the results obtained from at least two consecutive check samples show no positive tubes.

(4) The location at which the check samples were taken pursuant to paragraphs (d) (1), (2), or (3) of this section shall not be eliminated from future sampling without approval of the State. The results from all coliform bacterial analyses performed pursuant to this subpart, except those obtained from check samples and special purpose samples, shall be used to determine compliance with the maximum contaminant level for coliform bacteria as established in § 141.14. Check samples shall not be included in calculating the total number of samples taken each month to determine compliance with § 141.21 (b) or (c).

(e) When the presence of coliform bacteria in water taken from a particular sampling point has been confirmed by any check samples examined as directed in paragraphs (d) (1), (2), or (3) of this section, the supplier of water shall report to the State within 48 hours.

(f) When a maximum contaminant level set forth in paragraphs (a), (b) or (c) of § 141.14 is exceeded, the supplier of water shall report to the State and notify the public as prescribed in § 141.31 and § 141.32.

(g) Special purpose samples, such as those taken to determine whether disinfection practices following pipe placement, replacement, or repair have been sufficient, shall not be used to determine compliance with § 141.14 or § 141.21 (b) or (c).

(h) A supplier of water of a community water system or a non-community water system may, with the approval of the State and based upon a sanitary survey, substitute the use of chlorine residual monitoring for not more than 75 percent of the samples required to be taken by paragraph (b) of this section, *Provided*, That the supplier of water takes chlorine residual samples at points which are representative of the conditions within the distribution system at the frequency of at least four for each substituted microbiological sample. There shall be at least daily determinations of chlorine residual. When the supplier of water exercises the option provided in this paragraph (h) of this section, he shall maintain no less than 0.2 mg/l free chlorine throughout the public water distribution system. When a particular sampling point has been shown to have a free chlorine residual less than 0.2 mg/l, the water at that location shall be retested as soon as practicable and in any event within one hour. If the original analysis is confirmed, this fact shall be reported to the State within 48 hours. Also, if the analysis is confirmed, a sample for coliform bacterial analysis must be collected from that sampling point as soon as practicable and preferably within one hour, and the results of such analysis reported to the State within 48 hours after the results are known to the supplier of water. Analyses for residual chlorine shall be made in accordance with "Standard Methods for the Examination of Water and Wastewater," 13th Ed., pp. 129–132. Compliance with the maximum contaminant levels for coliform bacteria shall be determined on the monthly mean or quarterly mean basis specified in § 141.14, including those samples taken as a result of failure to maintain the required chlorine residual level. The State may withdraw its approval of the use of chlorine residual substitution at any time.

§ 141.22 Turbidity sampling and analytical requirements.

(a) Samples shall be taken by suppliers of water for both community water systems and non-community water systems at a representative entry point(s) to the water distribution system at least once per day, for the purpose of making turbidity measurements to determine compliance with § 141.13. The measurement shall be made by the Nephelometric Method in accordance with the recommendations set forth in "Standard Methods for the Examination of Water and Wastewater," American Public Health Association, 13th Edition, pp. 350–353, or "Methods for Chemical Analysis of Water and Wastes," pp. 295–298, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(b) If the result of a turbidity analysis indicates that the maximum allowable limit has been exceeded, the sampling and measurement shall be confirmed by resampling as soon as practicable and preferably within one hour. If the repeat sample confirms that the maximum allowable limit has been exceeded, the supplier of water shall report to the State within 48 hours. The repeat sample shall be the sample used for the purpose of calculating the monthly average. If the monthly average of the daily samples exceeds the maximum allowable limit, or if the average of two samples taken on consecutive days exceeds 5 TU, the supplier of water shall report to the State and notify the public as directed in § 141.31 and § 141.32.

(c) Sampling for non-community water systems shall begin within two years after the effective date of this part.

(d) The requirements of this § 141.22 shall apply only to public water systems which use water obtained in whole or in part from surface sources.

§ 141.23 Inorganic chemical sampling and analytical requirements.

(a) Analyses for the purpose of determining compliance with § 141.11 are required as follows:

(1) Analyses for all community water systems utilizing surface water sources shall be completed within one year following the effective date of this part. These analyses shall be repeated at yearly intervals.

(2) Analyses for all community water systems utilizing only ground water sources shall be completed within two years following the effective date of this part. These analyses shall be repeated at three-year intervals.

(3) For non-community water systems, whether supplied by surface or ground water sources, analyses for nitrate shall be completed within two years following the effective date of this part. These analyses shall be repeated at intervals determined by the State.

(b) If the result of an analysis made pursuant to paragraph (a) indicates that the level of any contaminant listed in § 141.11 exceeds the maximum contaminant level, the supplier of water shall report to the State within 7 days and initiate three additional analyses at the same sampling point within one month.

(c) When the average of four analyses made pursuant to paragraph (b) of this section, rounded to the same number of significant figures as the maximum contaminant level for the substance in question, exceeds the maximum contaminant level, the supplier of water shall notify the State pursuant to § 141.31 and give notice to the public pursuant to § 141.32. Monitoring after public notification shall be at a frequency designated by the State and shall continue until the maximum contaminant level has not been exceeded in two successive samples or until a monitoring schedule as a condition to a variance, exemption or enforcement action shall become effective.

(d) The provisions of paragraphs (b) and (c) of this section notwithstanding, compliance with the maximum contaminant level for nitrate shall be determined on the basis of the mean of two analyses. When a level exceeding the maximum contaminant level for nitrate is found, a second analysis shall be initiated within 24 hours, and if the mean of the two analyses exceeds the maximum contaminant level, the supplier of water shall report his findings to the State pursuant to § 141.31 and shall notify the public pursuant to § 141.32.

(e) For the initial analyses required by paragraph (a)(1), (2) or (3) of this section, data for surface waters acquired within one year prior to the effective date and data for ground waters acquired within 3 years prior to the effective date of this part may be substituted at the discretion of the State.

(f) Analyses conducted to determine compliance with § 141.11 shall be made in accordance with the following methods:

(1) Arsenic—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 95–96, Environ-

mental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(2) Barium—Atomic Absorption Method, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210–215, or "Methods for Chemical Analysis of Water and Wastes," pp. 97–98, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(3) Cadmium—Atomic Absorption Method, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210–215, or "Methods for Chemical Analysis of Water and Wastes," pp. 101–103, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(4) Chromium—Atomic Absorption Method, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210–215, or "Methods for Chemical Analysis of Water and Wastes," pp. 105–106, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(5) Lead—Atomic Absorption Method, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210–215, or "Methods for Chemical Analysis of Water and Wastes," pp. 112–113, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(6) Mercury—Flameless Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 118–126, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(7) Nitrate—Brucine Colorimetric Method, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 461–464, or Cadmium Reduction Method, "Methods for Chemical Analysis of Water and Wastes," pp. 201–206, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(8) Selenium—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," p. 145, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(9) Silver—Atomic Absorption Method, "Standard Methods for the Examination of Water and Wastewater", 13th Edition, pp. 210–215, or "Methods for Chemical Analysis of Water and Wastes", p. 146, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

(10) Fluoride—Electrode Method, "Standard Methods for the Examination of Water and Wastewater", 13th Edition, pp. 172–174, or "Methods for Chemical Analysis of Water and Wastes," pp. 65–67, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or Colorimetric Method with Preliminary Distillation, "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 171–172 and 174–176, or "Methods for Chemical Analysis of Water and Wastes," pp. 59–60, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974.

§ 141.24 Organic chemical sampling and analytical requirements.

(a) An analysis of substances for the purpose of determining compliance with § 141.12 shall be made as follows:

(1) For all community water systems utilizing surface water sources, analyses shall be completed within one year following the effective date of this part. Samples analyzed shall be collected during the period of the year designated by the State as the period when contamination by pesticides is most likely to occur. These analyses shall be repeated at intervals specified by the State but in no event less frequently than at three year intervals.

(2) For community water systems utilizing only ground water sources, analyses shall be completed by those systems specified by the State.

(b) If the result of an analysis made pursuant to paragraph (a) of this section indicates that the level of any contaminant listed in § 141.12 exceeds the maximum contaminant level, the supplier of water shall report to the State within 7 days and initiate three additional analyses within one month.

(c) When the average of four analyses made pursuant to paragraph (b) of this section, rounded to the same number of significant figures as the maximum contaminant level for the substance in question, exceeds the maximum contaminant level, the supplier of water shall report to the State pursuant to § 141.31 and give notice to the public pursuant to § 141.32. Monitoring after public notification shall be at a frequency designated by the State and shall continue until the maximum contaminant level has not been exceeded in two successive samples or until a monitoring schedule as a condition to a variance, exemption or enforcement action shall become effective.

(d) For the initial analysis required by paragraph (a) (1) and (2) of this section, data for surface water acquired within one year prior to the effective date of this part and data for ground water acquired within three years prior to the effective date of this part may be substituted at the discretion of the State.

(e) Analyses made to determine compliance with § 141.12(a) shall be made in accordance with "Method for Organochlorine Pesticides in Industrial Effluents," MDQARL, Environmental Protection Agency, Cincinnati, Ohio, November 28, 1973.

(f) Analyses made to determine compliance with § 141.12(b) shall be conducted in accordance with "Methods for Chlorinated Phenoxy Acid Herbicides in Industrial Effluents," MDQARL, Environmental Protection Agency, Cincinnati, Ohio, November 28, 1973.

§ 141.27 Alternative analytical techniques.

With the written permission of the State, concurred in by the Administrator of the U.S. Environmental Protection Agency, an alternative analytical technique may be employed. An alternative technique shall be acceptable only if it is substantially equivalent to the prescribed test in both precision and accuracy as it relates to the determination of compliance with any maximum contaminant level. The use of the alternative analytical technique shall not decrease the frequency of monitoring required by this part.

§ 141.28 Approved laboratories.

For the purpose of determining compliance with § 141.21 through § 141.27, samples may be considered only if they have been analyzed by a laboratory approved by the State except that measurements for turbidity and free chlorine residual may be performed by any person acceptable to the State.

§ 141.29 Monitoring of consecutive public water systems.

When a public water system supplies water to one or more other public water systems, the State may modify the monitoring requirements imposed by this part to the extent that the interconnection of the sysems jusifies treating them as a single system for monitoring purposes. Any modified monitoring shall be conducted pursuant to a schedule specified by the State and concurred in by the Administrator of the U.S. Environmental Protection Agency.

Subpart D—Reporting, Public Notification and Record Keeping

§ 141.31 Reporting requirements.

(a) Except where a shorter reporting period is specified in this part, the supplier of water shall report to the State within 40 days following a test, measurement or analysis required to be made by this part, the results of that test, measurement or analysis.

(b) The supplier of water shall report to the State within 48 hours the failure to comply with any primary drinking water regulation (including failure to comply with monitoring requirements) set forth in this part.

(c) The supplier of water is not required to report analytical results to the State in cases where a State laboratory performs the analysis and reports the results to the State office which would normally receive such notification from the supplier.

§ 141.32 Public notification.

(a) If a community water system fails to comply with an applicable maximum contaminant level established in Subpart B, fails to comply with an applicable testing procedure established in Subpart C of this part, is granted a variance or an exemption from an applicable maximum contaminant level, fails to comply with the requirements of any schedule prescribed pursuant to a variance or exemption, or fails to perform any monitoring required pursuant to Section 1445 (a) of the Act, the supplier of water shall notify persons served by the system of the failure or grant by inclusion of a notice in the first set of water bills of the system issued after the failure or grant and in any event by written notice within three months. Such notice shall be repeated at least once every three months so long as the system's failure continues or the variance or exemption remains in effect. If the system issues water bills less frequently than quarterly, or does not issue water bills, the notice shall be made by or supplemented by another form of direct mail.

(b) If a community water system has failed to comply with an applicable maximum contaminant level, the supplier of water shall notify the public of such failure, in addition to the notification required by paragraph (a) of this section, as follows:

(1) By publication on not less than three consecutive days in a newspaper or newspapers of general circulation in the area served by the system. Such notice shall be completed within fourteen days after the supplier of water learns of the failure.

(2) By furnishing a copy of the notice to the radio and television stations serving the area served by the system. Such notice shall be furnished within seven days after the supplier of water learns of the failure.

(c) If the area served by a community water system is not served by a daily newspaper of general circulation, notification by newspaper required by paragraph (b) of this section shall instead be given by publication on three consecutive weeks in a weekly newspaper of general circulation serving the area. If no weekly or daily newspaper of general circulation serves the area, notice shall be given by posting the notice in post offices within the area served by the system.

(d) If a non-community water system fails to comply with an applicable maximum contaminant level established in Subpart B of this part, fails to comply with an applicable testing procedure established in Subpart C of this part, is granted a variance or an exemption from an applicable maximum contaminant level, fails to comply with the requirement of any schedule prescribed pursuant to a variance or exemption or fails to perform any monitoring required pursuant to Section 1445(a) of the Act, the supplier of water shall given notice of such failure or grant to the persons served by the system. The form and manner of such notice shall be prescribed by the State, and shall insure that the public using the system is adequately informed of the failure or grant.

(e) Notices given pursuant to this section shall be written in a manner reasonably designed to inform fully the users of the system. The notice shall be conspicuous and shall not use unduly technical language, unduly small print or other methods which would frustrate the purpose of the notice. The notice shall disclose all material facts regarding the subject including the nature of the problem and, when appropriate, a clear statement that a primary drinking water regulation has been violated and any preventive measures that should be taken by the public. Where appropriate, or where designated by the State, bilingual notice shall be given. Notices may include a balanced explanation of the significance or seriousness to the public health of the subject of the notice, a fair explanation of steps taken by the system to correct any problem and the results of any additional sampling.

(f) Notice to the public required by this section may be given by the State on behalf of the supplier of water.

(g) In any instance in which notification by mail is required by paragraph (a) of this section but notification by newspaper or to radio or television stations is not required by paragraph (b) of this section, the State may order the supplier of water to provide notification by newspaper and to radio and television stations when circumstances make more immediate or broader notice appropriate to protect the public health.

§ 141.33 Record maintenance.

Any owner or operator of a public water system subject to the provisions of this part shall retain on its premises or at a convenient location near its premises the following records:

(a) Records of bacteriological analyses made pursuant to this part shall be kept for not less than 5 years. Records of chemical analyses made pursuant to this part shall be kept for not less than 10 years. Actual laboratory reports may be kept, or data may be transferred to tabular summaries, provided that the following information is included:

(1) The date, place, and time of sampling, and the name of the person who collected the sample;

(2) Identification of the sample as to whether it was a routine distribution system sample, check sample, raw or process water sample or other special purpose sample;

(3) Date of analysis;

(4) Laboratory and person responsible for performing analysis;

(5) The analytical technique/method used; and

(6) The results of the analysis.

(b) Records of action taken by the system to correct violations of primary drinking water regulations shall be kept for a period not less than 3 years after the last action taken with respect to the particular violation involved.

(c) Copies of any written reports, summaries or communications relating to sanitary surveys of the system conducted by the system itself, by a private consultant, or by any local, State or Federal agency, shall be kept for a period not less than 10 years after completion of the sanitary survey involved.

(d) Records concerning a variance or exemption granted to the system shall be kept for a period ending not less than 5 years following the expiration of such variance or exemption.

APPENDIX A—RESPONSE TO PUBLIC COMMENTS

Proposed National Interim Primary Drinking Water Regulations[1] were published for comment on March 14, 1975, 40 FR 11990. Written comments on the proposed regulations were invited, and public hearings were held in Boston, Chicago, San Francisco and Washington, D.C. Almost five hundred written submissions were received, totaling several thousand pages. Seventy-seven witnesses testified at the public hearings. In all, an aggregate of over 3,500 discrete comments were contained in the written submissions and in oral testimony.

As a result of these comments and further consideration of available data by EPA, a number of changes were made in the proposed regulations. The principal changes are summarized in the preamble to the final regulations. The purpose of Appendix A is to discuss the comments received on various aspects of the proposed regulations, and to explain EPA's response to those comments.

I. DEFINITIONS

1. *"Public Water System."* More than fifty comments were directed to the definition of "public water system" contained in § 141.1. Concern was expressed over the fact that the definition does not track the statutory definition word for word. Questions were also raised concerning the coverage of specific types of facilities with their own water systems, such as parks, schools, trailer camps and factories.

The reason for expanding the statutory definition was to express more specifically the Congressional intent. The statutory definition, contained in Section 1401(4) of the Public Health Service Act ("the Act"),[2] covers all systems with at least fifteen service connections or "regularly" serving at least 25 individuals. The term "regularly" is not explained in the statute, but the legislative history of the statute makes clear that Congress intended to cover virtually all public accommodations which have their own water supply and serve at least 25 individuals. The proposed regulations therefore explained "regularly" as meaning "daily at least three months out of the year." This three-month period has been shortened to 60 days in the final regulations because campgrounds and other public accommodations serving water for as much as 60 days during the year appear to fall within the classes of facilities Congress intended to cover. If a public water system serves the requisite number of service connections or persons for a total of 60 days during a calendar year, even if the service is intermittent, it is a public water system.

It is clear from the breadth of the definition of "public water system" in the Act and from the legislative history that the coverage of the Primary Drinking Water Regulations is not limited to traditional water utilities. Campgrounds, trailer camps, factories, parks, schools, restaurants, gasoline stations, motels and other facilities which have their own water systems must comply with the regulations if they serve the requisite number of service connections or the requisite number of persons.

Proposed § 141.3, entitled "Coverage," apparently contributed to confusion over the meaning of "public water system." That section, which was taken from section 1411 of the Act, exempts from the Primary Drinking Water Regulations, public water systems which meet four specified conditions. Over

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[1] The proposed regulations actually were designated "Interim Primary Drinking Water Standards." Because the Safe Drinking Water Act refers to "Regulations" rather than "Standards," the final version of the regulations does not use the term "Standards" in the title.

[2] Statutory authority for the adoption of Primary Drinking Water Regulations is derived from the Safe Drinking Water Act, Public Law 93–523, which added a new Title XIV to the Public Health Service Act. References to pertinent sections in the United States Code accordingly are to the Public Health Service Act rather than to the Safe Drinking Water Act.

50 comments were received on this section. In response to comments asking for clarification of the section, it has been revised to make clear that a public water system must meet each of the four listed conditions in order to be exempted from the regulations. Thus, a public water system is exempted only if it consists only of distribution and storage facilities and it obtains all of its water from, but is not owned or operated by, a public water system to which the regulations apply, and it does not sell water and it is not a carrier which conveys passengers in interstate commerce. Interstate carriers, therefore, are not exempted, even if they have only storage and distribution facilities, obtain all their water from a public water system, and do not sell water to the public. However, a public facility such as a hotel or restaurant is exempted if it has only storage and distribution facilities, obtains all its water from a public water system and does not sell water to the public.

Of course, many facilities serving transients obtain water by direct connection to a conventional water utility system and either do not constitute a separate system or are excluded from coverage because they meet all four of the conditions listed in § 141.3. And in some cases, such as gasoline stations, even when the facility has its own water system it often will not qualify as a public water system because it does not serve water to the requisite number of service connections or persons.

2. *"Community Water System."* Two comments requested clarification of the definition of a "community water system," § 141.2. The purpose of defining this term is to allow appropriate regulatory distinctions between public water systems which serve residents on a year-round basis and public water systems which principally serve transients or intermittent users. Different monitoring requirements are appropriate for the two types of systems, and, as discussed below, some maximum contaminant levels are not applicable to non-community systems.

The proposed regulations defined "community water system" as "a public water system which serves a population of which 70 percent or greater are residents." This definition distinguished community systems on the basis of service to residents, but it excluded a number of systems which serve a large number of residents throughout the year. For example, some large resort communities may have several hundred or even several thousand year-round residents who nevertheless make up less than 70 percent of the population of the community at any given time. Water systems in such communities should be treated as "community systems" in order to provide appropriate protection for the year-round residents in the community. Thus, the definition of a "community water system" has been revised to cover any system which serves at least 15 service connections used by year-round residents or serves at least 25 year-round residents.

A definition for "non-community system" has been added to make it clear that a public water system is categorized as being either a community or a non-community system.

3. *"Maximum contaminant level" and "contaminant."* Over 150 comments were directed to the definition of "maximum contaminant level" or the definition of "contaminant."

The definition of "contaminant" contained in § 141.2 was criticized for its breath. The term as defined includes virtually any constituent in water, including constituents considered to be harmless or even beneficial. The definition was taken directly from Section 1401(6) of the Act. It is not intended to suggest that all constituents in water are undesirable, but rather is intended to permit the regulation of any constituent which may be found to be harmful. The definition has been retained as proposed.

The definition of "maximum contaminant level" was criticized for requiring measurement of the level at the "free flowing outlet of the ultimate user of a public water system." This definition carries out the intent of Congress that "drinking water regulations are intended to be met at the consumer's tap." (H. Rep. No. 93-1185, 93rd Cong., 2nd Sess. 13 (1974)). The purpose of the Primary Drinking Water Regulations is to assure that water used by the public is safe. This can be assured only if maximum contaminant levels are met at the tap.

The final regulations retain the requirement that maximum contaminant levels be met at the consumer's tap, but have been amended to meet the point made in many comments that a public water system cannot be held responsible for contamination of water which is the fault of the consumer. It would be unreasonable to hold a public water system in violation of a maximum contaminant level if the level is exceeded at the consumer's tap as a result of the user's attachment of a faulty home treatment device, because of cross-connections in the user's plumbing system or because the plumbing is used to ground electrical systems. The definition of "maximum contaminent level" in § 141.2(d) therefore provides that "Contaminants added to the water under circumstances under the control of the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition." This wording is not meant to deter or to detract from the maintenance of a cross-connection control program by the supplier.

The proposed definition provides for measurement of turbidity at the point of entry to the distribution system, rather than at the consumer's tap, since measurement of turbidity at this point is a more meaningful indicator of the sanitary quality of the water.

4. *"Sanitary survey."* A definition of the term "sanitary survey" has been added as § 141.2(f), because sanitary surveys are referred to at several points in the final regulations. Comments from many sources, including the National Drinking Water Advisory Council, urged EPA to emphasize the importance of sanitary surveys of public water systems as a means of assuring that Primary Drinking Water Regulations will be met. The definition contained in the regulations reflects the broad extent of adequate sanitary surveys, including on-site review of the water source, facilities, equipment, operation and maintenance of a public water system.

5. *Other definitions*. Other comments were received on the definitions of "person" and "supplier of water". These defintiions were taken directly from section 1401 of the Act, and have been retained in the final regulations. As in the case of some comments on the definition of "public water system," a number of these comments were based on an erroneously restricted view of the coverage of the Act. As noted above, Congress intended that Primary Drinking Water Regulations apply to a broad range of facilities with their own water systems, not just to conventional water utilities. The owner or operator of a restaurant or motel, for example, is a "supplier of water" if the facility has its own water system and serves the requisite number of service connections or persons.

II. INORGANIC CHEMICALS

1. *General Comments*. Comments on maximum contaminant levels ("MCL's") for inorganic chemicals (§ 141.11) included questions on the analytical aspects of the MCL's—whether these were total or dissolved levels, whether the analytical methodology was adequate for the cited levels, whether an allowance had been made for analytical variations, and whether the public water system's laboratory or some other laboratory would be performing the analyses. The Administrator has verified that all of the substances for which MCL's have been specified can be measured readily by available methodology at the applicable levels. The analytical methods cited in these regulations provide information on analytical variability, and the check-sample and averaging techniques cited in § 141.23 provide additional allowances for human or mechanical errors. Two comments urged that MCL's for inorganic chemicals be deferred until issuance of the report of the National Academy of Sciences pursuant to Section 1412(e) of the Act. However, it was the intent of Congress that the Interim Primary Drinking Water Regulations be promulgated as soon as possible, so that at least minimal protection to water consumers would be available during the period that the Academy is preparing that report.

2. *Water consumption*. The MCL's for inorganic chemicals and other contaminants are based on an individual consumption rate of two liters of water per day. Fourteen comments agreed with the two-liter figure or contended that a lower figure should be used. Four comments urged the adoption of a higher consumption figure. An environmental organization submitted data indicating that some segments of the population, such as foundry workers and heavy drinkers, consume an average of susbtantially more than two liters per day.

EPA's assumption of a two liter per day water intake rate was based on evidence that the average consumption of adult males is at a rate of 1.25–1.5 liters per day and that the average consumption rate of women and children is even lower. Because Congress intended that susceptible groups in the population should be protected to the extent feasible, the use of a two-liter figure provides protection for the great majority of the population which consumes an average amount of water, or less than an average amount, or even as much as one-third more than the average amount. To base all maximum contaminant levels on the water consumption rate of the small percentage of the population which drinks much more water each day would be unrealistic and enormously expensive.

This is not to say that the maximum contaminant levels do not protect persons who drink water at a substantially higher rate than normal. As indicated below, critical maximum contaminant levels have substantial safety factors. The safety factors for persons drinking unusually large quantities of water are not as high as those for the majority of the population, but they do provide a reasonable degree of protection under the circumstances.

3. *Safety factors*. One set of comments questioned the fact that different safety factors are contained in various proposed maximum contaminant levels. The group commenting agreed that a uniform safety factor should not be used, but requested a more systematic discussion of safety factors at least with respect to inorganic chemicals.

The regulations are, as anticipated by Congress, based on the 1962 Public Health Service Standards, as reviewed in 1973 by the EPA Advisory Committee. The standards were not developed by a systematic approach to safety factors, at least partly because of amount of knowledge about, and the nature of the health risk of, the various contaminants covered a very broad range. The regulations are the result of experience, evaluation of the available data, and professional review.

In the Statement of Basis and Purpose for these regulations, the safety factor represented by a number of the maximum contaminant levels for inorganic chemicals was estimated. The purpose of this was to determine whether the estimated safety factor was roughly consistent with the type of information available and the nature of the health risk presented. It was not intended to rewrite the regulations on the basis of estimated safety factors.

The National Academy of Sciences has been asked to review each of the substances for which maximum contaminant levels are being set, as part of the NAS study for the adoption of Revised Primary Drinking Water Regulations. Any new information obtained by NAS on the safety factors involved will be carefully analysed by EPA.

4. *Arsenic*. Thirteen comments addressed the proposed MCL for arsenic (§ 141.11(a)). Most comments regarding arsenic recommended an MCL of 0.1 mg/l on the basis that no adverse health effects have been demonstrated from the consumption of water containing this amount.

The Administrator has considered raising the arsenic limit to 0.1 mg/l for the same reason cited in many comments—no adverse health effects have been demonstrated from consumption of water containing this amount or more, at least not in this country. However, arsenic has been shown to be a potential carcinogen in some of its forms in industrial exposures, and there appears to be a correlation between arsenic levels in drinking water and the occurrence of skin cancer in other countries. While the role of arsenic as a carcinogen or co-carcinogen has not been firmly established, it does not seem to be prudent at this time to raise the arsenic limit.

5. *Barium*. Two comments concerned the MCL for barium, and both expressed concern over required compliance when the MCL is exceeded as the result of naturally occurring barium in ground water.

Maximum contaminant levels apply equally to naturally occurring substances and those occurring as the result of man-made pollution. When barium is found to exist in a ground water source, the course of action is to attempt its removal, such as by conventional water treatment processes or ion exchange, or to obtain a different water source. If such action is not feasible, the system can seek a variance or exemption under the provisions of these and subsequent regulations.

6. *Cadmium*. Three comments suggested that the cadmium limit should be revised to allow more protection for cigarette smokers, while 49 comments emphatically denounced the concept of having non-smokers bear the financial burden of lowering the cadmium limit for the benefit of smokers. The Administrator is aware of the fact that smokers will be provided a smaller factor of safety on the basis of the cadmium limit, but he agrees with the majority that a reduction of the limit cannot be justified.

7. *Chromium*. The seven comments on the MCL for chromium included suggestions that the limit be raised, that it be eliminated, or that it be specified as only for hexavalent chromium.

The limit for chromium is based on the known toxicity of the hexavalent form. Since this form is the one most likely to be found in drinking water, and since the specified analytical detection method (atomic absorption spectrophotometry) does not distinguish between the valence states, the MCL is for total chromium. If part of the chromium present is in a lower valence state, the MCL provides an additional margin of safety.

8. *Cyanide*. There were only two comments on the MCL for cyanide—one stating that the MCL was too low and one stating that the limit was based on insufficient data. Since small amounts of cyanide do not constitute a health hazard, and since chlorination further reduces the toxicity of cyanide, this substance is rarely a problem in drinking water, and there appears to be no justification for including cyanide in the list of inorganic chemicals for which MCL's are established in these Regulations. Cyanide has not been identified during routine sampling of drinking water in concentrations greater than 1/10 of the proposed MCL, which itself is 1/100 of the level at which cyanide has adverse health effects on humans. It does not appear that there is justification for requiring tens of thousands of communities to monitor for this substance. Further, cyanide occurs, however rarely, in drinking water primarily as a result of spills or other accidents, which can be more appropriately controlled by other laws or regulations, such as Section 1431 of the Act. The Administrator, therefore, has decided to withdraw cyanide from the Interim Primary Drinking Water Regulations. The States may require monitoring for cyanide in appropriate circumstances.

9. *Lead*. The one comment on the MCL for lead stated that the limit is too low and that it is below or near the detection limit. The Administrator has verified that the atomic absorption spectrophotometric method specified has the necessary sensitivity for detection of the metal at the specified concentration.

10. *Fluoride*. The 94 comments on the fluoride MCL's covered an extremely broad area. Among the comments were suggestions that a single MCL of 0.05 mg/l, of 1.5mg/l, of 1.8 mg/l, of 2.0 mg/l, of 2.4 mg/l, of 2.5 mg/l, or of 5.0 mg/l be used in place of those in the regulations. There also were suggestions that different ranges be used, and that the reason for temperature-dependent MCL's be given. Some comments requested that fluoride be deleted from the regulations, or at least placed in Secondary Drinking Water Regulations. Quite a number of comments were directed toward controlled fluoridation rather than MCL's for fluoride. Some persons registered their objections to controlled fluoridation, while others requested that limits for controlled fluoridation be included in the regulations. There were comments that all fluoride should be removed from drinking water, and comments that there should be no limit on fluoride. There were comments that water supplies serving transients be excluded from the fluoride limits, and comments that educational institutions should not be excluded.

The fluoride question has been complicated by the fluoridation controversy. It was clearly the intent of Congress that Primary Drinking Water Regulations not be used as the vehicle for a national fluoridation program (House Report, p. 15). At the same time, Congress made it clear that there was no intent to prohibit or discourage fluoridation. As for changing the MCL's, either raising or lowering them, very little data were submitted to support the recommendations.

Suggestions that the MCL's be lowered were for the most part based on presumed toxicity of fluoride or on presumed increased exposure to fluoride from sources other than water. The evidence available to the Administrator indicates that the toxic effect of fluoride in drinking water is limited to mottling of dental enamel and minor changes in bone density, and that these effects occur primarily at fluoride concentrations above the proposed MCL's. It has been postulated that, with the advent of controlled fluoridation, the overall exposure of individuals to fluoride has increased to the point where the addition of more fluoride to drinking water is no longer necessary, or perhaps even to the point where lower MCL's in water ought to be established. While it is true that foods prepared in fluoridated water contribute fluoride to the diet in addition to that obtained from drinking water, it should be noted that the fluoride MCL's are based almost entirely on epidemiological evidence obtained from areas where fluoride is a natural constituent of the water. It can be assumed that in such areas most food was prepared in the local water, so the contribution of fluoride from this source was automatically taken into account;

This same epidemiological evidence showed that there is a temperature-dependent physiological effect of fluoride, both beneficial and detrimental depending on concentration. To ignore this evidence would seem to be most unwise. The use of a temperature scale for fluoride is more appropriate than for other chemicals because of the studies available on the fluoride-temperature relationship and because there is a small margin with fluoride between beneficial levels and levels with adverse health effects.

Suggestions that the MCL's be raised or eliminated were based on the interpretation of dental fluorosis as an esthetic condition rather than as a health problem or on the economic aspects of fluoride removal. The Administrator has available to him a wealth of information on the subject of fluorides, plus the advice and counsel of the dental experts at the National Institutes of Health, DHEW. On the basis of this information and counsel, the Administrator believes that the MCL's in these regulations are adequate for the protection of the health of consumers, and that there is insufficient evidence to justify altering the proposed MCL's. While the Administrator believes that the exemption of educational institutions from the fluoride limits was justified, revision of the regulations to exclude non-community public water systems from most inorganic chemical MCL's will make the exemption provision unnecessary.

11. *Mercury*. Six comments contained suggestions that the mercury limit be left as proposed except that it be applied only to methyl mercury; seven comments suggested that a limit be set for organic mercury only; and 29 comments expressed agreement with the proposed limit—a limit based on the health hazard of methyl mercury but measured as total mercury. One comment expressed dissatisfaction with mercury limits in general, on the basis that the mercury problem has been grossly exaggerated.

A specific limit for organic mercury, or designating the proposed limit as applicable only to organic mercury, both present problems in analysis, and do not provide for potential conversion of inorganic mercury to the organic form. Since the proposed limit for total mercury is based on the "worst case" concept, that is, presumes that all mercury present is in the more toxic, organic form, it provides maximum health protection. Because of the low levels of mercury found in drinking water, the economic impact of the proposed limit is expected to be minimal. The Administrator therefore is satisfied that the proposed limit for mercury is generally acceptable.

12. *Nitrate*. Most of the 21 comments on the nitrate MCL were directed toward naturally occurring nitrate and the difficulty in meeting the limit. As explained in the Statement of Basis and Purpose, nitrate can be toxic to infants. Because of the known adverse health effects of nitrate, the Administrator believes that an MCL for nitrate should be set. While it is acknowledged that removal of nitrate from drinking water is difficult, in many cases the sources of nitrate can be identified and steps taken to prevent its entry into drinking water sources. An example is the nitrate contamination of ground water as the result of surface run-off. Such contamination can often be eliminated by proper well construction.

13. *Sodium*. Several comments suggested the possibility of an MCL for sodium and the National Drinking Water Advisory Council recommended that consideration be given to

monitoring for sodium so that the public can be informed of the sodium content of available water. These concerns result from the fact that many persons in the United States suffer from diseases which are influenced by dietary sodium intake. In addition, persons may wish to limit their sodium intake for other reasons. However, EPA has not proposed an MCL for sodium, and the Advisory Council did not recommend an MCL, because the data available do not support any particular level for sodium in drinking water, and because regulation of sodium by an MCL is a relatively inflexible, very expensive means of dealing with a problem which varies greatly from person to person.

EPA has requested the National Academy of Sciences to include sodium in its study of the health effects of inorganic chemicals. In the meantime, the Agency recommends that the States institute monitoring programs for sodium, and that physicians and consumers be informed of the sodium concentration in public water systems so that they can take action they may consider appropriate.

14. *Sulfate*. Comments also were submitted urging the adoption of an MCL for sulfate. As in the case of sodium, the National Drinking Water Advisory Council recommended monitoring for sulfate levels, but did not recommend the adoption of a maximum contaminant level.

The sulfate question is similar to the sodium question in that available data do not support the establishment of any given level. A relatively high concentration of sulfate in drinking water has little or no known effect on regular users of the water, but transients using high sulfate water sometimes experience a laxative effect. Whether this effect will occur, and its severity, varies greatly with such factors as the level of sulfate in the water being consumed and the level of sulfate to which the transient is accustomed. EPA recommends that States institute monitoring programs for sulfates, and that transients be notified if the sulfate content of the water is high. Such notification should include an assessment of the possible physiological effects of consumption of the water.

The National Academy of Sciences has been asked to consider sulfate in its study. An MCL for sulfate will be proposed if it is supported by the available data.

15. *Inorganic chemical MCL's for non-community systems*. As proposed, the regulations would have made all MCL's for inorganic chemicals applicable to non-community water systems. This approach failed to take into account the fact that the proposed MCL's for inorganic chemicals, except nitrates and cyanide, were based on the potential health effects of full-time, long-term exposure. MCL's based on full-time long-term exposure are not necessary to protect transients or intermittent users served by non-community systems. Therefore, the final regulations provide that MCL's for inorganic chemicals other than nitrates are not applicable to non-community systems. Nitrates are applicable to all public water systems because they can have an adverse health effect on susceptible infants in a short period of time after exposure. (As discussed above, the other proposed inorganic chemical MCL based on short-term effects—cyanide—has been deleted.)

16. *Monitoring requirements*. Section 141.23, dealing with inorganic chemical monitoring requirements, received more comments than any other section of the proposed regulations. Altogether, there were over 300 discrete comments on inorganic chemical monitoring, with the largest segment of the comments being directed toward § 141.23 (b), the provision for increased monitoring when 75% of the maximum contaminant level is attained.

The comments on § 141.23(a) dealt mostly with the time interval allowed for compiling a historical record of water quality. Most comments contained the opinion that more time should be allowed for the "phasing in" of, particularly, the non-community water systems. On the other hand, there were comments to the effect that too much time had been allowed. There were a number of requests that non-community systems be exempted from the inorganic chemical monitoring requirements, on the basis that maximum contaminant levels are based on lifetime chronic health effects, and that users of non-community water systems are not exposed for a lifetime. There also were comments requesting that no distinction be made between different types of water systems, such as surface and ground. As noted above, because MCL's for inorganic chemicals have, in most cases, been based on chronic health effects for lifetime exposures, they will not be applied to non-community systems. Therefore, § 141.23 has been rewritten to indicate that, except for nitrates, inorganic chemicals monitoring will be required only for community water systems.

Virtually every comment on § 141.23(b) expressed criticism of the concept of increased monitoring when a contaminant level reaches 75% of the maximum allowed. Reasons given were that such monitoring imposes "a safety factor on top of a safety factor," that the State should determine when increased monitoring frequency is desirable, that analysis for some constituents would be impossible because of the limits of detection, that analytical costs would be prohibitive, that ground water contaminant levels are not variable, and that the proposed monitoring frequency was too demanding. Some commentors suggested that less frequent monitoring be allowed when a contaminant level was below 50% of the MCL.

Section 141.23(b) was written with the intent that, when a contaminant level reached 75% of the MCL, monitoring frequency would be increased so that the supplier of water would have an adequate warning of possible or impending violation of the MCL. By thus being forewarned, the supplier of water could take corrective measures before violation occurred. In light of the comments received, it has been concluded that although such sampling may be a matter of good operating practice, it is not appropriate for inclusion in a primary drinking water regulation for the reasons stated in the comments. Therefore, the Administrator has decided to withdraw § 141.23(b). However, the Administrator believes it would be prudent for the operator of a community water system to increase monitoring frequency for a contaminant which appears to be approaching the MCL, and for the States to direct such increased monitoring when appropriate.

Comments on § 141.23(c) were largely directed toward the requirement that sampling and analysis be repeated within 24 hours after determination that an MCL has been exceeded. It was felt that this did not allow enough time, and in fact there was some misunderstanding as to whether it was intended that only the resampling be completed within 24 hours or that both resampling and reanalysis be completed in this time frame. Section 141.23(c) has been rewritten to indicate that when a sample result does not comply with the MCL, the supplier of water shall initiate three additional samples within one month. Since compliance will be judged on the average of these four samples initiated over a one-month period, the requirement that the first check sample be either completed or initiated within 24 hours is not justified.

Section 141.23(d) elicited a number of comments in regard to the definition of a "moving average," and there were general objections to the public notification provision. The opinions expressed were that the public should be notified only if the violation of an MCL involved an imminent hazard to health, or that emphasis should be placed on correcting a problem rather than increasing the monitoring frequency and notifying the public. The rewording of section 141.23(c) to provide for a one-month average has eliminated the need for paragraph (d). The one-month average provides a less complicated, more efficient means of determining compliance.

In regard to public notification of noncompliance with an MCL, Section 1414(c) of the Act requires that notice of such noncompliance be conveyed to the public. The nature of the corrective measures to be taken are determined by the supplier of water and the State. The comments on § 141.23(e), the special provisions for nitrate, were directed toward the 24-hour re-analysis requirement and the concept of the special provision itself. Most comments contained the opinion that no re-analysis could be performed in the time allotted, and others questioned the basis for singling out nitrate for special consideration. Nitrate was singled out for special consideration among the inorganic chemicals because of the acute toxicity of nitrate to infants. The resampling requirement has been rewritten for improved clarity.

The comments on § 141.23(f) dealt entirely with the suggestion that alternative analytical methods be allowed. As noted above, alternative analytical techiques may be permitted by the State if the substitute method is substantially equivalent to the techniques prescribed in this regulation, in both precision and accuracy, as it relates to the determination of compliance with any maximum contaminant level.

III. ORGANIC CHEMICALS

1. *CCE*. Section 141.12, maximum contaminant levels for organic chemicals, received over 80 comments. Most of these comments criticized the carbon chloroform extract (CCE) method for estimation of organic chemical contamination. Criticisms of the CCE requirement were based on cost, lack of correlation with health effects, inadequacy as a measure of total organic chemical content, inapplicability to ground water, and lack of supporting data. Some comments suggested an alternative surrogate for organic chemical contamination, including total organic carbon and chemical oxygen demand. Other comments concerning CCE were that it be considered for inclusion in the Secondary Drinking Water Regulations, that there be provision for raising the MCL when the organics content of water is shown to be harmless, and that a treatment technique be substituted for the MCL. Over twenty comments requested that the CCE procedure be dropped altogether. Three comments requested that the limit be lowered.

The general problem of organic chemicals in drinking water is accorded top priority by EPA. Concern over organic chemicals was one of the principal reasons for passage of the Safe Drinking Water Act. Surveys conducted by EPA in recent months indicate that manmade organic chemicals are present in small amounts in water supplies in many parts of the country. The Agency is committed to using the regulatory tools provided by the Act to deal with the potential adverse health effects of organic chemicals in drinking water.

The proposed use of a CCE maximum contaminant level was an attempt to deal with gross organic pollution as soon as possible pending the results of further research, surveys and the NAS study. CCE was initially used as a means of taste and odor control. As concern over adverse health effects of organic chemicals grew, CCE was turned to as a rough surrogate for organics to be used as a health-based standard rather than as an esthetic standard. Unfortunately, as more is learned about organic chemical pollution of drinking water, CCE looks less and less effective as a surrogate for harmful organics.

The principal difficulty with CCE is that it includes only about one-tenth of the total organic content of the volume of water sampled and it does not measure organic compounds of greatest concern, such as the volatile halomethanes. Thus, a high CCE test result does not necessarily mean that the water tested may pose a hazard to health, and a low CCE test result may be obtained from water with a high level of potentially harmful organic compounds. In short, there is no sound basis of correlation between CCE test results and the level of harmful organic chemicals in the water tested.

To establish a maximum contaminant level under these circumstances would almost certainly do more harm than good. It could give a false sense of security to persons served by systems which are within the established level and a false sense of alarm to persons served by systems which exceed the level. It also would divert resources and attention from efforts to find more effective ways of dealing with the organic chemical problem.

Total organic carbon (TOC) and chemical oxygen demand (COD) are surrogates that have been considered, but they have limitations also. TOC has the advantage of being quicker and cheaper (on a per sample basis) than CCE, but the availability of sensitive instruments for this measurement is questionable. More investigation of the significance of any TOC number as a health effects limit is also needed. COD is easily determined with readily available laboratory equipment, but COD is not limited to organic compounds, and besides a COD number also cannot be adequately related to health significance at this time.

EPA is diverting substantial resources to research into the health effects of specific organic chemicals and groups of organic chemicals. Also, it is expected that the study of the National Academy of Sciences will produce further data on health effects. However, in view of the significance of the potential health problem, it is not enough to wait for this additional health effects data. EPA therefore will undertake to identify one or more surrogate tests for organic chemicals or organic chemical groups, and will also study in depth the presence of specific organic chemicals in drinking water supplies. It is anticipated that this effort will result in the development of an additional MCL or MCL's for organic chemicals by amendment of the Interim Primary Drinking Water Regulations without having to wait for a more complete resolution of the organic chemicals-question in the Revised Regulations.

Accordingly, EPA is adopting regulations on organic chemical monitoring, using the authority of Sections 1445 and 1450 of the Act. The regulations require that over 100 selected public water systems serving substantial populations collect samples of raw and treated water for submission to EPA for organics analysis. EPA will analyze the samples for a number of general organic parameters, including CCE, TOC (volatile and nonvolatile), NVOC, Total Organic Chlorine (TOCl), ultraviolet absorbancy, and fluorescence. In addition, the water will be analyzed for 21 specific organic compounds. These laboratory analyses will be used to evaluate the extent and nature of organic chemical contamination of drinking water, to evaluate the validity of the general organic parameters as surrogates for measures of harmful organic chemicals, and to determine whether there is an adequate basis for establishing maximum contaminant levels for specific organics or groups of organics.

In addition, EPA is embarking on an intensive research program to find more definitive answers to the following four questions:

1. What are the effects of commonly occurring organic compounds on human health?

2. What analytical procedures should be used to monitor finished drinking water to assure that any primary drinking water regulations dealing with organics are met?

3. Because some of these organic compounds are formed during water treatment, what changes in treatment practices are required to minimize the formation of the compounds in treated water?

4. What treatment technology must be applied to reduce contaminant levels to the concentrations that may be specified in the regulations?

This research will involve health-effects and epidemiological studies, investigations of analytical methodology, and pilot plant and field studies of organic removal unit processes. Some phases of the research are to be completed by this fall, while much of the remainder is to be completed within the next calendar year.

As soon as sufficient information is derived from the monitoring program and related research, primary drinking water regulations will be amended so that the organic chemicals problem can be dealt with without delay. The monitoring program will be completed within one year.

During the interim period while satisfactory MCL's for organic contamination in drinking water are being developed, EPA will act in specific cases where appropriate to deal with organic contamination. If the EPA monitoring program reveals serious specific cases of contamination, EPA will work with State and local authorities to identify the source and nature of the problem and to take remedial action. EPA will also aid the States in identifying additional community water supplies that require analysis.

2. *Pesticides*. Proposed § 141.13 contained MCL's for several organic pesticides. Most of the comments on § 141.13 (out of a total of 130) requested that the MCL's for pesticides either be raised or deleted entirely. There were two requests for inclusion of limits for 2,4,5-T, one request for an organophosphate insecticide limit, one for a limit on dioxin, and requests for limits for aldrin, dieldrin, DDT and chlorine (sic.) Other comments suggested that pesticide limits be restricted to emergencies or spills, or at least only to surface water during periods of pesticide use. There were also requests for research on carcinogenic risk and bioamplification.

These proposed pesticides levels were carefully considered by the Advisory Committee and have been reviewed in light of available data on the health effects of these pesticides and their incidence in drinking water supplies. The levels established are adequately supported by the authorities cited in the Statement of Basis and Purpose.

A limit for 2,4,5-T was tentatively proposed by the Advisory Committee but was deleted from the Committee's final report in 1973 on the grounds that EPA's ban on the use of 2,4,5-T for aquatic uses made a drinking water limit unnecessary. That ban has now been in effect for about five years, and it is highly unlikely that this herbicide exists in drinking water except perhaps in extremely rare cases in trace amounts. EPA is now investigating reports of 2,4,5-T in some waterways in Northern Louisiana, and will reconsider the desirability of an MCL for 2,4,5-T if new data indicate that the pesticide is appearing in drinking water supplies at a significant rate. Dioxin is a minor contaminant of 2,4,5-T, and the same basic considerations apply to it.

The desirability of an MCL for organophosphorus insecticides, which was recommended in 1973 by the Advisory Committee, was carefully considered by EPA. It was decided not to adopt such a level, because although these pesticides would pose a serious health risk if they were present at the consumer's tap, the fact is that there is no evidence that such pesticides reach the consumer's tap. This was discussed in the preamble to the proposed primary drinking water standards, at 40 FR 11992. As noted there, these pesticides reach water sources usually only by accident or indirectly, and their tendency to degrade rapidly apparently has prevented problems which might occur when they do reach drinking water sources. The principal threat from these pesticides is from accidental spills in water sources. The appropriate way to deal with such spills is by emergency action when they occur, not by periodic monitoring which would not catch the problem in time.

With respect to aldrin, dieldrin and DDT, EPA's national survey of the presence of these pesticides in drinking water supplies has not been completed. If the results of that survey indicate that those pesticides are present in a significant number of water supplies, an appropriate amendment of the Interim Primary Drinking Water Regulations will be proposed.

The proposed MCL's for chlordane, heptachlor, and heptachlor epoxide have been deleted bceause EPA is currently involved in suspension and cancellation hearings for these pesticides. MCL's will be reconsidered at a later date.

Current research on pesticides, including both surveys of their incidence in water supplies and their health effects, will be continued and expanded.

3. *Monitoring Requirements*. There were over 250 comments on § 141.24, dealing with monitoring for compliance with the MCL's for CCE and pesticides. However, most of these comments were more related to the merits of the MCL's than to the monitoring requirements. The CCE limit has been discussed above, and that discussion will not be repeated here.

A number of comments on § 141.24 suggested that monitoring requirements for pesticides be eliminated, or at least that the responsibility for such monitoring be assumed by EPA or the States rather than by public water system. Concern was expressed over the cost of monitoring for pesticides, and the absence of pesticides in public water systems in some areas.

EPA agrees that regular monitoring for pesticides is not needed for all public water systems using only ground water sources. Pesticides are rarely found in significant levels in ground water. Accordingly, the proposed §141.24 has been amended to provide that for a system using only ground water, monitoring shall be required only when specified by the entity with primary enforcement responsibility. This will more reasonably limit monitoring for pesticides in systems using only ground water to those instances when the State or EPA has reason to suspect the possibility of contamination.

In the case of surface waters, the greater incidence of these pesticides requires monitoring across-the-board. For all community water systems using surface water sources for all or part of their water, monitoring for pesticides will be required within one year of the effective date of the regulations. This monitoring shall be repeated at intervals specified by the State and in no event less frequently than at three year intervals.

Section 1424 has also been amended to require that samples to be analyzed for pesticides must be collected during a period of the year designated by the entity with primary enforcement responsibility as the period when contamination by pesticides is most likely to occur. This takes into account the fact that the level of pesticides in surface waters varies on a seasonal basis in relation to agricultural uses of the pesticides. This amendment will make monitoring for pesticides in drinking water more effective.

Several comments criticized proposed § 141.24(b), which would have required increased monitoring when the contaminant level reaches 75% of the MCL. This is basically the same question addressed above with respect to monitoring requirements for inorganic chemicals. For the same reasons, the 75% increased monitoring requirement for pesticides has been eliminated.

Other comments requested that EPA allow alternative analytical procedures. A new § 141.27 has been added to provide that a supplier of water may, with State approval, employ an alternative analytical technique.

There appears to have been some misunderstanding regarding the role of the public water system laboratory versus State or other laboratories in performing analyses for the purpose of determining compliance with these regulations, and in particular the MCL's for pesticides. Although it is intended that the individual suppliers of water be responsible for the analyses, it was not intended that each supplier of water necessarily possess the analytical capability to perform the analyses himself. It is reasonable to expect each supplier of water without its own laboratory facilities will collect and transmit water samples to approved laboratories.

It should be noted that with respect to organic chemicals and other contaminants, all MCL's and monitoring requirements in these regulations are minimum requirements, and it is incumbent on the entity having primary enforcement authority to require additional monitoring and other requirements where appropriate.

IV. Turbidity

1. *Turbidity MCL's*. About half of the more than 160 comments on the MCL for turbidity (§ 141.14) contained a request that turbidity be deleted from the Primary Drinking Water Regulations or be relegated to the Secondary Drinking Water Regulations. There were also requests that the MCL be raised, that there be a limit of 5 turbidity units ("TU") and a "goal" of 1 TU, and that the MCL be lowered. Other comments referred to turbidity in sub-arctic waters, the use of a two-level MCL for turbidity, and the apparent encouragement of chlorination.

The Administrator has determined that turbidity is indeed appropriately classified as a health limit, in that turbidity has a marked effect on the bacteriological quality of water, whether or not disinfection is practiced.

As noted above, many comments questioned the need for a turbidity limit applicable to systems using only a ground water source. In this regard the Administrator believes that in most cases, turbidity is not a problem in properly developed wells. In some cases, excess sand is included in the water pumped but this is not a health related problem. In other cases dissolved iron present precipitates upon oxidation. This also is not a health related problem. In some fractured geologic formations and particularly in limestone formations, turbidity could be a periodic problem because of a short retention times in the aquifer. In these cases the State is encouraged to take appropriate action in establishing a limit or treatment requirement.

Some comments questioned the proposal to allow an MCL of 5 TU rather than 1 TU in cases where the entity with primary enforcement responsibility specifically authorized the higher MCL. The Administrator believes this is justified on the basis that not all turbidity is related to bacteriological quality. Examples of instances where the higher turbidity may be allowed are when iron or other minerals, or minute ice crystals in otherwise satisfactory water, are the cause of the turbidity. Proving that a particular type of turbidity does not interfere with disinfection or does not interfere with microbiological determinations is not always easy. One of the best methods for proving the former is an accumulation of data showing good bacteriological quality in the distribution system over an extended period of time, even with turbidity over 1 TU. A microbiologist can, by various manipulative techniques, tell whether or not turbidity is interfering with the coliform test. No doubt a State may employ other means for determining when a public water system has qualified for the higher turbidity limit.

The proposed regulations measured the turbidity MCL only on the basis of a monthly average. The National Drinking Water Advisory Council recommended that a supplementary MCL be established to protect against the appearance of a particularly high turbidity level over a short period of time. In accordance with the Council's recommendation, § 141.13 has been amended to establish an MCL of 5 TU as an average of two consecutive daily samples. EPA agrees with the Council that turbidity levels above 5 TU cannot be justified in surface waters for more than a one-day period.

That there is an implied endorsement of chlorination in these regulations cannot be denied. The Administrator, recognizing chlorination as being the only generally available disinfectant in water treatment, has on several occasions specifically endorsed chlorination as a valuable public health measure. Pending further research, the possible long-term adverse effects of chlorination are in most cases offset by the effectiveness of chlorination for preventing bacteriological contamination.

2. *Turbidity Monitoring*. There were over 120 comments on the turbidity monitoring requirements (§ 141.22). Most of the comments were directed toward the requirements as they applied to water supplies using water from underground sources. It was agreed that turbidity in ground water need not be monitored, and in fact there were a number of comments suggesting that turbidity monitoring be deleted altogether. There were comments that the sampling was too frequent, and comments that in some circumstances the sampling was too infrequent. The question of cost was brought up in connection with sampling frequency. There also were requests for clarification of the entire section, with particular emphasis on defining an "entry point" to a distribution system.

It was the intent of the Administrator that public non-community water systems using ground water be exempted from the turbidity monitoring provisions. Unfortunately, however, the omission of commas in § 141.22(c) made it appear that only community systems using ground water were required to monitor for turbidity. The section has been written so that the turbidity monitoring requirements apply only to water systems using surface water sources. Also, for non-community systems using surface water, the regulations have been modified to require that the turbidity monitoring must be initiated within 2 years of the effective date.

The measurement of turbidity at the entry point to the distribution system, rather than at the consumer's tap, can be justified on at least two bases. First, since turbidity can be controlled only by water treatment processes, it is most appropriately measured immediately after the water has been treated, and before the measurement is affected by scale, sediment or other materials present in pipelines. Second, since one of the principal purposes for limiting turbidity is the fact that turbidity interferes with disinfection, and since disinfection is effected at the treatment plant, turbidity at the consumer's tap is not an adequate reflection of conditions where disinfection is taking place.

Comments suggesting an increased sampling frequency for turbidity in effect were suggesting operational monitoring desirable in specific cases rather than a frequency which is practical when generally applied to thousands of public water systems. It should be reiterated that these regulations contain only minimum requirements, and that more frequent monitoring can be required by EPA or the States in appproriate cases. Furthermore, there is nothing in these regulations to deter a supplier of water from more frequent turbidity monitoring as an operational guide.

Other comments on turbidity monitoring stated that the proposed requirements were too expensive. However, the cost and effort involved in measuring turbidity are not excessive. This is one parameter which can be, and in fact must be, measured by the individual suppliers of water. Almost anyone can learn to take turbidity measurements, and only a few seconds are required for each measurement. The only cost is in the purchase of a turbidimeter, which lasts for many years.

In order to take into account the fact that turbidity measurements in most cases will not be taken by trained laboratory technicians and that erroneous high readings can be obtained by careless handling of the test, § 141.22(b) has been amended to provide that if the initial daily sample appears to exceed the maximum allowable limit but a repeat sample shows a lower turbidity, the results of the repeat sample shall be used rather than the results of the initial sample.

Because turbidity is closely interrelated with filtration and disinfection, sampling is to be done at "a representative entry point(s) to the water distribution system." This means at a point between the filters and the mains. A clear well would be appropriate, as would be a point between a pump discharge and the mains if there are no filters. In the event that there are several "entry points," such as would be the case when there are several well pumps, a sampling point common to all pump discharges would obviate the necessity to sample at each pump discharge. If there is a question as to whether or not a particular sampling point were "representative" of the water being delivered to the distribution system, the State would make the decision. Alternative analytical procedures, such as continuous turbidity monitors, may be used at the discretion of the State.

V. Microbiological Limits

1. *Coliform Limits and Standard Plate Count*. There were almost 140 comments on § 141.15, Maximum Microbiological Contaminant Levels, of which about half were directed toward § 141.15(b), the standard plant count ("SPC"). Most of the comments on § 141.15(a), coliform limits, were general in nature, covering such points as clarification of the language, use of alternative indicator organisms, raising or lowering the limits, averaging of results, and the assignment of responsibility for performing the tests. Nearly all the comments on the SPC expressed opposition to the imposition of a maximum contaminant level. Opposition was based on the lack of health significance of the SPC and the unfavorable cost-benefit ratio.

Section 141.15(a) has been rewritten for clarification. The Administrator believes the coliform group of organisms are the best indicators of bacteriological quality of drinking water, although of course research into possible alternative indicators is ongoing. The Administrator also believes the maximum contaminant levels for coliform organisms are adequate to protect the health of consumers. Other limits for bacteriological quality, such as those in the World Health Organization Drinking Water Standards, may appear to be more stringent and thus more protective of health, but it must be remembered that WHO Standards are merely guidelines, not enforceable regulations. It should also be remembered that the currently proposed regulations contain minimum standards of quality, and that lower levels of contaminants should be attained when feasible. Because of the effect a single sample may have on a monthly average, particularly when only a few samples are examined per month, quarterly averaging will be allowed for those public water systems serving populations of 3300 or less.

Although the Administrator has evidence that the Standard Plate Count does have health significance, and in addition is a valid indicator of bacteriological quality of drinking water, the Administrator has deleted § 141.15(b). Because the coliform limit provides adequate protection against microbiological contamination, the cost of an SPC requirement cannot be justified. However the Administrator recommends that the SPC measurement be applied judiciously wherever indicated, if only as an operational tool, in conjunction with the coliform test.

2. *Chlorine Residual Substitution*. There were over 170 comments on § 141.16, the chlorine residual substitution provision. The comments represented overwhelming opposition to total substitution with concomitant suspension of the coliform test. There were also comments on the analytical procedure, free chlorine residual versus combined residual, and particular opposition to the concept of allowing substitution in the smaller communities. In the latter case, it was stated that a small community would not have a water system operator of sufficient skill or dedication to monitor chlorine residuals accurately or faithfully. There were several questions regarding the different chlorine residuals specified in §§ 141.16(a) and 141.16 (b). Some believed the residual should be raised, while others believed the lower residuals should be permitted.

The chlorine residual substitution provision was inserted so that in those communities where chlorination is practiced, some economic benefits might be realized by the deletion of part of the coliform testing requirements without affecting the health protection provided. In the smallest communities, total substitution of chlorine residual testing would result in a significant economic benefit, since it is in these communities that the maintenance of adequate water quality has the highest per capita cost. The Administrator believed that the maintenance of an adequate chlorine residual in a distribution system throughout a month was at least equivalent, in health safety terms, to isolated coliform tests. In the event that total substitution had been allowed by the State, the slightly higher chlorine residual provided a greater factor of safety.

It is true that a chlorine residual alone does not guarantee the absence of pathogenic bacteria. It is also true that a negative coliform test does not always guarantee the absence of pathogenic bacteria. However, the Administrator concedes that, because of questionable reliance on unskilled operators in the smallest communities, it would not be prudent to permit 100% substitution of chlorine residual testing for coliform tests in those cases. For this reason, proposed § 141.-16(b) has been deleted. However, 75% substitution will be permitted where specifically authorized by the entity with primary enforcement authority.

The analytical method specified for chlorine residual testing led to some misunderstanding. The DPD method, as described in "Standard Methods of Examination of Water and Wastewater," appears to be an involved and sophisticated procedure. It was specified primarily on the basis of accuracy and sensitivity, particularly when compared with the o-tolidine procedure in common use. The latter has been shown to be inaccurate and unreliable, but remains popular because of its simplicity and the ready availability of field test kits. What is not known, apparently, is that the DPD test is almost as simple and is also available in reasonably priced field test kits.

Chlorine substitution has been specified, rather than "disinfection substitution," simply because there is no other disinfection procedure of comparable safety and reliability. Iodination has been suggested, but iodine presents a health risk to some persons.

3. *Microbiological Monitoring*. There were over 250 comments on § 141.21, microbiological contaminant monitoring requirements, of which over 70 comments were directed toward § 141.21(g), the standard plate count monitoring requirement. Although both increased and decreased sampling frequencies for coliforms were requested, by far the greater number of comments expressed the opinion that the requirements of this section were unreasonably burdensome, particularly for the smaller communities and non-community public water systems. There were also numerous requests for clarification or modification of the coliform monitoring requirements, such as requests to modify the time for resampling, requests to permit exclusion of sampling points which have been shown to be contaminated, and requests to permit discarding positive bacteriological sampling results for which the check sample results are negative. In regard to § 141.21(g), the standard plate count monitoring requirement, most comments reflected the objections to the parameter itself rather than objections to the frequency of monitoring.

Considerable attention has been given to the sanitary surveys and monitoring frequency for coliforms, particularly in the case of small community systems or non-community systems. The concept of a sanitary survey, expressed in a number of comments, can be considered as a factor in determining the sampling frequency for a particular system. The practicality of sanitary surveys, at annual or even less frequent intervals, versus the collection and analysis of two water samples per month, must be carefully considered on both economic and manpower requirements. It has been estimated that there are 200,00 non-community water systems in this country, but from the information supplied in the comments received it is evident that this number may be too conservative. An adequate sanitary survey of each of these systems in one year would create a severe strain on the skilled manpower necessary.

The consensus of opinion from the States is that, in the event a sanitary survey becomes acceptable for establishing coliform sampling frequency for any segment of public water systems, a priority scheduling of surveys will be established, with populations at risk and known trouble spots being factors to consider. With such priorities, it is evident that the non-community systems, serving small population groups and delivering water on which there is no past record, will be last to receive attention. For this reason, among others, the paragraph on coliform monitoring, § 141.21(a), has been re-written to establish a minimum sampling frequency of one per calendar quarter for non-community systems. A sanitary survey can be used as a basis for modifying the sampling frequency. For the smaller community public water systems, a new population range has been delineated, with an accompanying reduction in coliform sampling frequency. In this range (25–1,000 persons served) one sample per month is the minimum, although the State may, based on a sanitary survey verifying certain conditions, reduce the sampling frequency, except that in no case shall it be reduced to less than one per quarter. In addition, the paragraph has been re-written to clarify the intent and to spell out more precisely the means by which compliance or non-compliance is determined.

An effort has also been made to clarify the samples that should be included and excluded among those used to calculate compliance. In this regard, a paragraph has been added on "special purpose samples", to define those used to check such operations as pipe disinfection procedures.

For non-community systems, in order to ease the laboratory work load, and provide a phased approach, the bacteriological monitoring requirement must be implemented within 2 years after the effective date of the regulations. This provides a 2 year period for the suppliers, State agencies, and laboratories to prepare for the greatly increased number of samples to be analyzed.

In response to the request to permit the elimination from future sampling of those points that have a history of questionable water quality, the wording has been modified to state that any sampling point at which check samples have been required may not be eliminated from future sampling without approval of the State.

Concern has been expressed that in some cases, because of either a sampling or a laboratory error, a microbiological analysis could result in an erroneously large count. The regulations require that this result be included among those samples used in calculating the average monthly coliform bacteria density, even though the subsequent check samples may have been all negative. This high count could cause the supplier to fail the monthly average and thus require that he notify the public.

The Administrator understands this problem, but cannot agree that the one "bad" sample should not be included in calculating the average. The reason is that there is no way to confirm that the bacteriological result of a sample collected in the past was due to sampling or analytical error. It cannot be accomplished, for example, by collecting a check sample, which by the length of the standard test, would have to be collected at least one day after the original sample. The check sample would not necessarily reflect the bacterial situation of the previous day. The only way to confirm bacterial sampling results are to collect and analyze samples in duplicate or triplicate.

Since there is no provision for discarding or adjusting for occasional spurious results from sampling or analytical error, EPA recommends that for positive bacterial analyses standard analytical verification methods be used to verify analytically that coliform bacteria are present.

As stated earlier, the standard plate count requirement has been deleted, although it is recommended that the parameter be employed as conditions warrant.

VI. LABORATORY CERTIFICATION

There were over 100 comments on § 141.27 dealing with laboratory certification. In general, there was agreement with the concept of laboratory certification, although there were a few requests for clarification of the role of the certifying authority. Most of the comments contained objections to the concept of requiring turbidity and chlorine residual tests to be performed by certified laboratories. The remaining comments addressed the cost of certification, the need for time to get labs certified, and the scarcity of qualified laboratories.

It was the intent of the Administrator that EPA would certify at least one laboratory in each State with other laboratories to be certified by the State laboratory or laboratories qualified to perform this function. Because of the transient nature of turbidity and chlorine residual values, it is not possible for a public water system to collect samples and transmit them to a central laboratory for determination of these parameters. It was the intent of the Administrator that the individual operators of public water systems perform their own turbidity and chlorine residual analyses. It would seem advisable, however, that such operators be certified, approved, or at least minimally trained to perform the analytical tasks before a State could accept their analytical determinations as having enough validity for decisions regarding compliance or noncompliance to be made.

VII. Reporting and Public Notification

1. *Reporting*. There were over 200 comments on § 141.31, dealing with reporting requirements, but only three basic criticisms; the reporting requirement should be limited to those situations which are essential to enforcement of the regulations; the section needs clarification; and the institution of reporting requirements makes compliance with the regulations either difficult or impossible. Minor comments included requests for changes in the 36-hour and 40-day reporting requirements, requests for a corrective action requirement rather than a reporting requirement, and requests that Federal agencies report to the States rather than to EPA.

Section 1413 of the Public Health Service Act deals with the role of the States in implementing and enforcing drinking water regulations. Section 1414 of the Act spells out actions to be taken if a State fails to assure enforcement of drinking water regulations. A State could not effectively comply with the provisions of these sections without receiving regular reports from every public water system within its jurisdiction. Monitoring frequencies have been established, and if only violations of maximum contaminant levels were reported the State would not know whether or not monitoring frequencies had been adhered to. Thus all activities of a supplier of water in connection with these regulations are essential to enforcement of the regulations and must be reported to the State.

It is apparent from Section 1447 of the Public Health Service Act and the legislative history of the Safe Drinking Water Act that Federal agencies are to be treated exactly like any other owner or operator of a public water system, except in cases involving national security. Therefore, the Administrator believes that it would be contrary to the intent of the Act to require Federal agencies to report only to EPA and not to States with primary enforcement responsibility. In the revision of § 141.31 of these regulations, no exemption for Federal agencies from the provisions of the regulations will be specified.

2. *Public Notification*. Section 141.32, the public notification provision, received a large number of comments. Of the more than 300 comments, only two approved of this section as written. Two additional comments contained suggestions for modification, such as, for example, to require a second notice to tell the public that the condition previously reported had now been corrected. Every other comment expressed opposition to public notification, either on the basis of disagreement with the concept, on the basis of inappropriateness for some types of water systems, or on the basis of some type of inequity. Most frequently heard comments were: the State should have the authority to notify consumers only if there is an immediate and significant threat to public health; scare tactics will lead to public disregard; notification by radio and TV within 36 hours is an unreasonable requirement; notification of the entire public is unreasonable when only a portion of the public is involved; and notification by means of water bills is unacceptable. One of the more constructive comments was that, while the concept of public notification was opposed, the supplier of water should be given the opportunity to explain the deficiency.

To explain the intent of Congress in requiring public notification, the following is quoted from House Report No. 93-1185:

"The purpose of this notice requirement is to educate the public as to the extent to which public water systems serving them are performing inadequately in light of the objectives and requirements of this bill. Such public education is deemed essential by the Committee in order to develop public awareness of the problems facing public water systems, to encourage a willingness to support greater expenditure at all levels of government to assist in solving these problems, and to advise the public of potential or actual health hazards."

The Administrator agrees that the supplier should be given the opportunity to explain the deficiency. It was not the intent of Congress, that such notices would be merely a flat statement that the water system had failed to meet the requirements of the Regulations. To quote the House Report further:

"the Committee expects that the Administrator's regulations would permit public water systems to give fair explanation of the significance or seriousness for the public health of any violation, failure, exemption or variance. These regulations should also permit fair explanation of steps taken by the system to correct any problem."

The wording has therefore been modified to permit that the supplier may use the notice to explain the significance or seriousness of the violation, to include the results of additional (subsequent) sampling, and to indicate preventative measures that should be taken by the public.

As to the unreasonableness of allowing only 36 hours prior to radio and TV notification, this wording has been modified to read 48 hours and the Administrator believes that this is adequate time to prepare such notification when an MCL is violated.

Time requirements for notification in newspapers has been established. The regulations require that the failure of any MCL shall be published in a daily newspaper or newspapers of general circulation in the area served by the system, on not less than three consecutive days, and that such notification is to be completed within seven days after the supplier learns of the failure. The notice shall be provided to radio and television stations within 48 hours after he learns of the failure.

Public notice for other failures of the regulations, such as failure to comply with testing procedures, failure to comply with monitoring requirements, and failure to comply with a schedule prescribed pursuant to a variance or exemption, is to be made by including a notice with the water bills, within at least three months after the supplier learns of the failure. In the event water bills are not issued, there is a provision for using another form of direct mail.

The provision for mailing notices responds at least in part to the comment that the notice should not be made to the entire public but only to the portion of the public using the water. Otherwise, it is true that a notice given in a newspaper of general distribution, or a radio or television broadcast, will reach more people than those affected by a particular public water system.

There is no way that this can be avoided, but there is nothing in the regulations which would prevent the notice from specifying which person or which area need be concerned about the notice.

The Administrator agrees that the proposed public notice provisions are inappropriate for non-community water systems. Notices in the local media and in water bills will not have the intended effect with these systems serving transients or intermittent users. Therefore, § 141.32 has been revised to include a provision for other types of notification, subject to approval by the State, for non-community water systems. Envisioned here are such types of notification as a poster or sign near the drinking fountain of a facility serving the travelling public, or a handbill distributed to factory workers.

VIII. Economic Considerations

There were over 100 comments on the economic aspects of the regulations. The two most frequent comments were that the estimates in the preamble were much too low, and that the economic impact on the smaller water utilities would be severe. The corrective measure suggested in most cases was that EPA should give grants to the public water systems or should provide funds to the States to pay for monitoring. In general, the comments contained criticisms of the regulations in that they were termed "not cost effective."

It was the intent of Congress that the bulk of the costs associated with the Safe Drinking Water Act would be borne by the individual public water systems and thus the consumers. Of all the comments on the cost of a program to improve the quality of drinking water, it is noteworthy that only one comment stressed the benefits to those consumers.

There is no doubt that money will be spent for increased monitoring. This is particularly true for the smaller water systems, where in the past practically no monitoring has been performed. These very small water systems are the ones which most need improvement, so it can be expected that the costs will be proportionately higher for the small systems when compared with larger systems. On a per capita basis, since so few customers are involved, the costs will be disproportionately higher for the smaller systems. Congress did not intend that the monitoring costs for these systems would be subsidized. Rather, Congress hoped that many small systems would be consolidated into larger systems, so that the costs would be shared by a larger number of consumers, and so that improved drinking water quality would more easily be attained.

A cost and economic analysis of the monitoring requirements are attached as Appendix B.

IX. Other Comments

1. *Siting*. Of the more than 70 comments on § 141.41, siting requirements, most either wanted the section deleted or else clarified in some way. The criticisms were that the requirements for siting were not realistic, that the terms used needed definitions, that State

approval be granted before a change in a water system be made, or that State approval is already required in the circumstances. The limitation regarding the "100-year flood" was criticized on the basis that water intakes (for surface water sources) must be in the floodplain. Suggestions included: use the words "geological hazards and man-made disasters;" add the phrase "avoid causing adverse environmental impacts;" and limit the provisions to "ground level or underground storage facilities, vertical wells of a system which has no filtration or any other treatment facilities."

It should be pointed out that the section on siting requirements in these regulations is flexible, in that the phrase "to the extent practicable" allows considerable leeway. These minimum siting requirements were included on the basis of section 1401 (1) (D) of the Public Health Service Act, which states: "The term 'primary drinking water regulation' means a regulation which contains * * * requirements as to (ii) siting for new facilities for public water systems." Obviously, some clarification of even these minimal requirements is called for, so the section has been revised. In accordance with Congressional intent, the revised version makes clear that all final siting decisions are to be made at the State and local government level.

2. *Effective date*. There were only three comments on § 141.51, the effective date of these regulations. All of these comments contained the request that more time be allowed for water systems, particularly those of small communities, to come into compliance.

The effective date of these regulations was established by section 141.12(a) (3) of the Public Health Service Act, which provides that, "The interim primary regulations first promulgated under paragraph (1) shall take effect eighteen months after the date of their promulgation." The Administrator believes that, by scheduling the monitoring requirements in several phases, ample consideration has been given to small systems. Variances and exemptions will be available in appropriate cases.

3. *Radionuclides*. There were approximately 50 comments relating to maximum contaminant levels for radionuclides. However, EPA only proposed MCL's for radionuclides on August 14, 1975, 40 FR 34324. Comments on radionuclides will be taken into account in that rulemaking proceeding.

4. *Water treatment chemicals*. Ten comments addressed chemical requirements in connection with the proposed regulations. The comments stated that certain chemicals, particularly activated carbon and filter grade alum, are in short supply.

It is acknowledged that an increase in the extent of water treatment will cause an increased demand for water treatment chemicals. If a particular treatment technique were to be specified, the demand for any chemical involved in that treatment technique could increase dramatically. Since no treatment in lieu of a monitoring requirement was specified in these regulations, the problem has not surfaced as yet. Before specifying any treatment technique, the Administrator will investigate both the availability of the necessary chemicals and the costs associated with that treatment technique. Naturally, the effect of an increased demand for a particular chemical on the cost of that chemical will also be investigated. Because of the phasing of the provisions of the Safe Drinking Water Act, and because there is currently no shortage of raw materials for the production of water treatment chemicals, it can be expected that ample quantities of these chemicals will be available for conventional water treatment when they are needed.

5. *Treatment techniques*. On the subject of treatment techniques or treatment technology, 30 comments contained criticisms or suggestions. It was noted that no treatment techniques were specified in lieu of MCL's, and almost unanimous support for this approach was expressed. On the other hand, it was suggested that information on treatment technology to remove certain contaminants be supplied.

While no treatment technique requirement was included in these regulations, the Administrator may specify such techniques in revised regulations if warranted. The Administrator believes, however, that it is always preferable to specify monitoring requirements if at all possible, because of the uncertainties involved in a treatment technique. Although a treatment technique may appear to be capable of removing a particular contaminant, based on laboratory or pilot plant studies, in actual water plant operation such removal may not always occur. Without monitoring, the adequacy of the treatment technique cannot be ascertained. As for technology for the operation of a conventional water treatment plant, operation and maintenance regulations are to be published separately. Techniques to be used for the removal of specific contaminants are the subject of ongoing research.

6. *Miscellaneous*. Comments not classified elsewhere addressed a number of miscellaneous topics, including the following: typographical errors, regulations for the quality of intake water, control of pollutants at the source rather than in drinking water, training of water plant operators and the encouragement of young people to enter the water treatment field, control of watersheds as a means for improving the drinking water quality, amending the regulations to eliminate systems serving less than 200 people, setting of priorities according to size and type of system when applying the regulations, regulations for interconnections of supplies, provision of technical support by the Environmental Protection Agency Regional Offices, and the development of a policy on carcinogens as an aid to standard setting.

APPENDIX B—COST AND ECONOMIC ANALYSIS EXECUTIVE SUMMARY [1]

1.0 *Safe Drinking Water Act of 1974*. The objective of the Safe Dranking Water Act (Pub. L. 93-523) is to establish standards which will provide for safe drinking water supplies throughout the United States. To achieve this objective the Congress authorized the Environmental Protection Agency to establish national drinking water regulations. In addition, the Act provides a mechanism for the individual States to assume the primary responsibility for enforcing the regulations, providing general supervisory aid to the public water systems, and inspecting public water supplies.

The purpose of the legislation is to assure that water supply systems serving the public meet minimum national standards for the protection of public health. Prior to passage of the Act, the Environmental Protection Agency was authorized to prescribe Federal drinking water standards applicable only to water supplies used by interstate carriers. Furthermore, these standards could only be enforced with respect to contaminants capable of causing communicable diseases. In contrast, the Safe Drinking Water Act authorized the Environmental Protection Agency to establish regulations to (1) protect public water systems from all harmful contaminants; (2) protect underground sources of drinking water; and (3) promote a joint Federal-State system for assuring compliance with these regulations.

1.1 *National interim primary drinking water regulations*. The EPA published its Proposed National Interim Primary Drinking Water Regulations in the FEDERAL REGISTER, March 14, 1975. The EPA held four public hearings and received several thousand pages of public comments on the proposed regulations. Based upon its review of the comments, the EPA revised the proposed regulations for final publication. The major provisions of the Interim Primary Drinking Water Regulations are:

1. Maximum contaminant levels for certain chemical, biological, and physical contaminants are established;

2. Monitoring frequencies to determine that contaminant levels assure compliance are established; and

3. A methodology to notify consumers of variances, exemptions, and non-compliance with standards is set forth.

1.2 *The Water Supply Industry*.

1.2.1 *Public Water Systems*. The Safe Drinking Water Act of 1974 covers public water systems that regularly serve an average of 25 people or have at a minimum 15 service connections. Systems that serve the travelling public are considered public water systems under the Act. EPA currently estimates there are 240,000 public water systems that will be subject to the regulatory requirements developed under the Act.

The Interim Primary Drinking Water Regulations categorize public systems as community and non-community systems. A community system is defined as a public system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. The non-community system category includes those systems which serve a transient population. At the present time the distribution between the two classes of public systems is estimated as follows:

Community systems	40,000
Non-community systems	200,000
Total	240,000

Based on the data contained in the ongoing EPA public water supply inventory, there are approximately 177 million persons served by community water systems. Table 1-1 shows the distribution of community systems by population served. Most of the community water systems are small in size. Over 90 percent of the nation's supplies are in the under 10,000 persons-served category but they provide water to less than 25 percent of the total population served by community systems.

While all public systems do not treat all of the water they supply to their customers, they do employ a variety of treatment processes. The current EPA Inventory of Public Water Supplies indicates that the most prevalent treatment processes are used to control bacteriological contamination and turbidity. The percentage of systems employing the various treatment processes is presented in Table 1-2.

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[1] This summary is based on a detailed and comprehensive study prepared for EPA by Energy Resources Company of Cambridge, Massachusetts, titled, "Economic Evaluation of the Interim Primary Drinking Water Regulations" (October 1975).

TABLE 1-1.—*Distribution of community water systems*

System size (persons served)	Number of water systems	Total population served (in thousands)	Percent of total population served
25 to 99	7,008	420	0.2
100 to 9,999	30,150	36,810	20.8
10,000 to 99,999	2,599	61,420	34.6
100,000 and over	243	78,800	44.4
Total	40,000	177,450	100.0

Source: EPA Inventory of Public Water Supplies (July 1975).

TABLE 1-2.—TREATMENT PROCESSES EMPLOYED BY COMMUNITY WATER SYSTEMS

Treatment:	*Percent* (¹)
Aeration	6.6
Prechlorination	7.8
Coagulation	11.3
Sedimenation	8.9
Filtration	12.8
Softening	4.9
Taste and odor control	3.4
Iron removal	5.7
Ammoniation	0.9
Fluoride adjustment	8.5
Disinfection	35.2

[1] Percentages do not total 100 percent since many systems have multiple treatments, or no treatment.

Source: EPA Inventory of Public Water Supplies (July 1975).

Community water systems may be publicly or privately owned. The majority, 58 percent, of the 40,000 community water supplies are publicly owned and these systems supply 88 percent of the total drinking water production.

As indicated earlier, it is estimated that there are approximately 200,000 public non-community water systems. Most of these systems are privately owned. Non-community systems are found at service stations, motels, restaurants, rest areas, camp grounds, State parks, beaches, national parks, national forests, dams, reservoirs, and other locations frequented by the travelling public. Some schools and industries are also included in this category. Data on these systems are very sparse, and only rough cost estimates can be made.

The portion of the water supply industry considered here includes only those systems which primarily supply water for residential, commercial, industrial and municipal use. An approximate allocation of water use by various categories of users is shown in Table 1-3. As might be expected most of the water delivered, 63 percent, is for residential purposes. The second largest use, industrial, consumes 21 percent.

TABLE 1-3.—COMMUNITY WATER SUPPLY USE BY CATEGORY

Type of use:	*Percentage of total*
Residential	63
Commercial	11
Industrial	21
Municipal	5
Total	100

Source: U.S. Geological Survey Data (1972)

1.3 *Costs to meet the interim primary drinking water regulations.*

1.3.1 *Monitoring costs.* The implementation of the Interim Primary Drinking Water Regulations will require all public water systems to initiate a monitoring program to determine that the maximum contaminant level requirements of the regulations are not exceeded in finished drinking water. The costs associated with this monitoring activity are a function of system size, water source, and classification (community vs. non-community).

There are two classes of monitoring costs, routine monitoring costs and non-compliance monitoring costs, imposed by the interim regulations. Routine monitoring costs are those incurred in meeting the sampling requirements of the Interim Primary Drinking Water Regulations, to determine compliance with the regulations. Non-compliance monitoring costs are those which are incurred when additional sampling must be made if routine monitoring results indicate that a system is not in compliance with one or more maximum contaminant limit.

The Interim Primary Drinking Water Regulations call for the monitoring of four classes of contamination: inorganic, organic, microbiological, and turbidity. The routine monitoring frequencies for community and non-community systems are shown in Tables 1-4 and 1-5.

TABLE 1-4.—*Monitoring requirements: Community supplies; interim primary drinking water regulations*

Component	System type	Deadline for initial sampling after effective date	Testing frequency
Coliform	Ground and surface	1 mo	Monthly.[1]
Inorganic chemicals	Surface	1 yr	Annually.
	Ground	2 yr	Every 3 yr.
Organic chemicals	Surface	1 yr	(²).
	Ground	As specified by the State	As specified by the State.
Turbidity	Surface	1 d	Daily.

[1] Supplies must collect minimum required samples during each month after effective date. The number of samples varies with the system size from 1 to 500 samples per month.

The State may reduce the sampling frequency based on a sanitary survey of a system that serves less than 1,000 persons from a groundwater source, except that in no case shall it be reduced to less than one per quarter.

[2] The analyses shall be repeated at intervals specified by the State but in no event less frequentlythan at 3-yr intervals.

TABLE 1-5.—*Monitoring requirements: Noncommunity supplies; interim primary drinking water regulations*

Component	System type	Deadline for initial sampling after effective date	Testing frequency
Coliform	Surface and ground	2 yr	Quarterly.[1]
Inorganic chemicals—nitrates only.	Surface and ground	do	Determined by the State.
Turbidity	Surface	do	Daily.

[1] May be modified by the State based on sanitary survey.

In developing routine monitoring costs, the number of systems requiring routine monitoring is fixed by the number of ground and surface water supply systems in each discrete size range and the monitoring frequency prescribed by the regulations. Therefore, the only variable in the cost equation is the price per analysis. This price will depend on the institutional arrangements made by each system for analytical services. At the present time some water supplies perform their own analyses, while others depend on State health agencies or private commercial laboratories. The unit analytical costs developed for the monitoring costs estimates are as follows:

Analysis:	*Cost range*
Coliform	$5–10
Complete inorganic	70–170
Complete organic	150–260

The lower costs are based on costs incurred in EPA laboratories while the higher costs are based on commercial laboratory estimates.

In developing non-compliance monitoring costs, the critical variable is the number of additional samples required when a system exceeds a maximum contaminant level (MCL). The interim regulations require a minimum of two check samples when the coliform MCL is exceeded and at least three repeat samples when an inorganic or organic MCL is exceeded. In each instance the supplier must continue the sampling procedure until two consecutive samples show that the MCL is not exceeded. For coliform violations it is expected that from 2 to 5 special analyses may be needed. For organic and inorganic violations it is expected that from 3 to 6 special analyses may be necessary.

The estimated costs for routine and special monitoring for public water systems are summarized in Table 1–6. In the first year of implementation the annual costs are expected to fall in a range of $14 million to $30 million. By the end of the third year when the non-community systems begin to monitor, the annual monitoring costs will rise to a range of $17 million to $36 million. These monitoring cost estimates do not reflect the costs of existing monitoring programs. Current routine monitoring is estimated at approximately $10 million to $17 million annually.

TABLE 1-6.—*Total monitoring costs mandated by the interim primary drinking water regulations*

[In millions of dollars]

	1st year	2d year	3d year
Cost of routine monitoring for the 40,000 community systems[1]	13.30-27.3	12.70-26.3	12.3-25.5
Monitoring due to violations of MCL for 40,000 community systems:			
(i) Coliform violation monitoring	.50- 2.0		
(ii) Inorganic violation monitoring	.01- .3	.01- 0.3	
Routine monitoring costs for 200,000 public systems[2]			4.5- 9.4
Monitoring due to violations of MCL for 200,000 public systems[3]			.3- .8
Total	14.00-30.0	13.00-27.0	17.0-36.0

[1] Annual costs beginning the 1st year after implementation of the regulations.
[2] Annual costs beginning the 3d year after implementation of the regulations.
[3] Total monitoring costs due to violations spread over a 5-yr period.

NOTE.– Totals may not add due to rounding.

1.3.2 Treatment costs. Once the monitoring program is initiated, some systems will find that they exceed one or more maximum contaminant levels (MCL). These systems will then be faced with an additional cost in order to meet the required MCL. There are several alternative routes which a system can pursue in order to comply with the Regulations. Some of the alternatives include:

1. Installing treatment facilities capable of reducing the MCL to an acceptable level;

2. Developing a new source of supply of better quality;

3. Purchasing better quality water from another water utility; or

4. Merging the system with one or more adjoining systems which have a higher quality supply.

If none of the above are feasible, a system can apply for a variance or exemption to the MCL under the provisions of the Interim Primary Regulations. Therefore, the costs incurred by a water supply in reducing the concentration of a contaminant to an acceptable level are site specific and will depend on such factors as, treatment facilities available, age of system, proximity of other suppliers, source of water, and many other inter-related problems.

However, in projecting national costs for treatment the option of installing treatment facilities was assumed to be the method systems would select to provide safe drinking water.

The following basic assumptions are implicit in developing costs for the treatment options:

1. Surface water systems not presently clarifying will install some form of filtration;

2. Approximately 30 percent of the community water systems not presently disinfecting will install chlorination units;

3. Advanced treatment is necessary to remove inorganics;

4. Estimates of the number of MCL violations were based on 1969 Community Water Supply Study, except for mercury. Mercury violations were based on recent EPA studies.

The national treatment costs for public water systems are summarized in Table 1–7. The majority of costs, if all systems elect to treat for contaminant violations, will be incurred in order to meet the turbidity and inorganic requirements of the interim regulations. Ranges were developed for capital costs only. This range is based on making two assumptions for daily flow. If a system were required to install treatment, it would have to consider sizing their new components to reflect average daily flow conditions or maximum daily flow conditions in cases where system storage is not adequate. Whatever sizing option a system selected it is unlikely that significant additional operation and maintenance expenses would result.

TABLE 1–7.—*National costs of treating contaminants in drinking water*

[In millions of dollars]

Treatment technology	Contaminant	Capital costs	Annual operation and maintenance
Community systems:			
Clarification	Turbidity	379– 683	189
Chlorination	Coliform	17– 27	7
Ion Exchange	Ba, Cr, Cd, NO^3, Hg, Se	619– 997	53
Activated alumina	As, fluoride	31– 53	11
pH Control	Pb	3– 4	.1
Subtotal		1049–1764	259
Non-community systems:			
Clarification	Turbidity	10	1
Chlorination	Coliform	14	3
Subtotal		24	4
Total		1073–1788	263

NOTE.—Totals may not add due to rounding.

1.4 *Economic impact of the interim primary drinking water regulations*

The expenditures required to comply with the Interim Primary Regulations will have an impact on all water users served by public water supplies covered by the Safe Drinking Water Act. All persons served by these systems will feel the impact of monitoring costs to some extent. However, the most noticeable impact of the regulations will be on users of public water systems that do not meet the MCL requirements of the regulations.

An estimate of the total annual costs of capital, operation and maintenance, and monitoring necessary to comply with the Regulations is shown in Table 1–8.

TABLE 1–8.—ESTIMATED TOTAL ANNUAL COSTS OF IMPLEMENTING THE INTERIM PRIMARY DRINKING WATER REGULATIONS FOR PUBLIC WATER SUPPLY SYSTEMS IN MILLIONS OF DOLLARS [1]

Annual capital [2]	146–247
Annual operation and maintenance	263
Annual monitoring (routine only)	17–35
Total annual	426–545

[1] 1975 dollars.

[2] Assumes capital costs amortized over 15 years at 7-percent interest.

1.4.1 *Water supply economics*. The price consumers pay for water is determined, in general, by costs the utility incurs to operate and maintain the system. However, some publicly-owned water systems may have their costs and revenues conglomerated with the cost of other municipal services, and the water bill paid by the consumer may not completely reflect the status of the water system alone.

Water system rate structures vary from system to system, and may also differ for various user classes within the same system. There are four basic types of rate structures which are used around the country. Some systems use a "normal block" structure which results in lower unit costs to customers that use high volumes of water. In the "inverted block" structure, higher units costs are imposed upon customers who use higher volumes of water. Under a "flat" rate structure, there is one single charge per unit for all customers regardless of use. Generally, the flat rate structure applies to residential customers only. Finally, in the "non-incremental" rate structure, the unit cost of water is based on the number of water consumption units owned by the user.

Prices charged for water are usually regulated by a State or local commission appointed to evaluate the need for rate hikes. In most States, investor-owned utilities are under the jurisdiction of State regulatory commissions. Publicly-owned utilities are either regulated by local boards or are unregulated. Any lengthy lag time between rate increase requests and rate increase approvals may pose problems in the implementation of the interim regulations.

Most water utilities, both public and private, finance large capital investments by retaining profits or acquiring debt. Publicly-owned systems may have access to municipal funds or can sell either general obligation or revenue bonds to be repaid from general revenues or water revenues. Private, investor-owned systems may issue stocks and bonds, and unlike publicly-owned systems, their credit ratings are dependent on the profitability of their own operations. Since interest rates are generally proportional to risk, water utilities in more secure financial positions can borrow money at lower interest rates. At the present time the interest rates on municipal bonds is 4–6 percent while the rate for debt issues of private-owned utilities is 6–8 percent.

In the water industry there does not seem to be a correlation between present debt levels and long-term financial soundness. Although a majority of water systems today have debt ratios ranging upward from 40 percent, almost one-fourth of the water systems are presently debt-free. Approximately 85 percent of these debt free systems serve communities of less than 5,000 people. However, many of these small systems do not have a positive net income, while larger water systems with high debt to book value ratios do have positive net income.

Records indicate that per capita consumption of water tends to decrease following significant increases in water rates. Among individual users the decrease would occur where there is a high elasticity of demand; e.g., lawn sprinkling. Industrial and commercial users have shown no elasticity to price increases. If demand declines sharply after initial rate hikes and total revenues do not increase enough to cover increased cost, a second rate increase may be necessary.

1.4.2 *Per capita costs*. Monitoring costs vary with the size of the water system involved. The number of samples for routine bacteriological monitoring is a function of the number of persons served. For community supplies the number of samples can range from a minimum of 1 sample per quarter for systems serving 1000 people or less to a maximum of 500 samples per month for systems serving more than 4,690,000 people. For non-community supplies only one sample per quarter is required.

In general, the annual impact of routine chemical monitoring will vary depending on the frequency of sampling rather than the number of samples. The frequency of sampling will depend on the system type: ground water vs. surface water; community system vs. non-community. The annual monitoring costs on a per capita basis are shown in Table 1–9. The per capita costs for the smallest community system (25 persons served) are high in comparison to other system sizes. However, there are very few systems in this category and the States may desire to enter into institutional arrangements to lessen their annual monitoring burden.

TABLE 1–9.—*Annual monitoring costs per person served versus system size and type for community water system*

System size	System type	
	Surface	Ground
25	$7.20–$15.05	$3.85–$7.05
100	1.80– 3.75	.85– 1.75
500	.35– .75	.15– .35
1,000	.20– .40	.10– .20
2,500	.15– .30	.05– .10
5,000	.10– .25	.05– .15
10,000	.10– .20	.05– .15
100,000	.05– .15	.05– .15
1,000,000	(1)– .05	(1)– .05
10,000,000	(1)	(1)

[1] Less than $0.05.

However, treatment costs may be responsible for much higher per capita cost increases than monitoring costs. As indicated earlier, public water systems not meeting the MCL requirements of the interim regulations will incur the major cost burden. The impact of the treatment costs will also vary with the size of the water system involved. Table 1–10 summarizes the treatment costs as they affect systems of different sizes.

It should be pointed out that the per capita costs displayed in Table 1–10 are weighted averages. Treatment costs have been weighted by the projected frequency of the various treatment techniques within each size subcategory. By its nature, the weighted average does not give a true representation of the costs to a particular consumer. In all categories, there are five treatments possible with a wide variation in costs. In Table 1–11, the range of annual per capita monitoring and treatment costs are presented. From this table it can be seen that the annual per capita treatment costs for disinfection are expected to range from $3.85 to $2.10 in the Smallest system category, from $2.75 to $0.30 in the Small system category and so on.

	Smallest systems (25 to 99 people served)	Small systems (100 to 9,999 people served)	Medium systems (10,000 to 99,999 people served)	Large systems (over 100,000 people served)
Annual capital costs (in millions)	$3.80- $6.40	$60.20-$101.40	$52.30- $88.10	$30.50-$51.20
Annual operation and maintenance costs (in millions)	2.10	48.00	74.10	184.10
Annual monitoring costs (in millions)	.30- .60	.90- 1.30	1.20- 2.50	1.30- 2.90
Total annual costs (in millions)	6.20- 9.10	109.40- 151.90	127.60- 164.70	165.90- 198.30
Weighted average cost per capita per year	37.00- 54.00	11.00- 15.60	9.00 - 12.00	10.00- 11.00
Increase in household monthly water bill[1]	9.60- 14.05	2.85- 3.95	2.35- 3.05	2.55- 2.90

[1] Assumes 3.11 persons per household and that all increases in costs are passed on to the consumer.

TABLE 1-11.—*Annual per capita treatment and monitoring cost ranges for 4 size categories*

	Smallest systems (25 to 99 people served)	Small systems (100 to 9,999 people served)	Medium systems (10,000 to 99,999 people served)	Largest systems (over 100,000 people served)
Treatment:[1]				
Disinfection	$3.85- $2.10	$2.75-$0.30	$0.45-$0.15	≤$0.25
Turbidity control	152.00- 52.00	78.00-16.00	20.00-12.50	≤15.00
Heavy metal removal	227.00-101.00	142.00-25.50	35.00-18.00	≤18.00
Lead control	2.60- 1.20	1.80- .30	.40- .20	≤.30
Fluoride/arsenic removal	11.80- 7.85	11.30- 3.15	5.00- 3.15	≤3.55
Monitoring	15.80- .85	3.75- .05	.20- .05	≤.15

[1] Lower cost limit based on assumption that treatment plant built to treat average daily demand and upper cost limit based on maximum daily demand, except for the smallest systems category where costs are based on average daily demand only.

1.4.3 *Impact analysis.* As Table 1-10 and Table 1-11 demonstrate, the potentially most severe impact could occur for users of the smallest or small systems. Assuming that treatment and monitoring costs are directly passed on to the consumer, the monthly water bill for a household in the smallest systems, may increase on the average between $10 and $14.

However, as noted earlier, these systems may choose not to install treatment facilities in order to comply with the regulations. Several options are available to them:

1. Developing a new, less contaminated source;
2. Joining a regional system;
3. Purchasing treated water; or
4. Blending water from existing source with water of higher quality.

The exemption and variance provisions of the Act provide for temporary immunity from the regualtions on the basis of economic hardship or technical difficulties. Federal loan programs may also ease the impact on users of small systems. The Farmers Home Administration sponsors a loan and grant program to aid the financing of water and sewer system construction in small communities. The loans are offered at low interest rates and with long repayment schedules. The Safe Drinking Water Act also authorizes a loan guarantee program for small systems. These programs will reduce community costs, but they will not completely mitigate the possibility of high cost impacts on households in small systems.

It is not certain how systems will finance the costs associated with these regulations—either through higher taxes or higher water rates—but it is certain that the Interim Drinking Water Regulations will have the gratest impact on those served by smaller water systems. Further study is underway to determine if financing will be a serious problem for large or small systems.

At the present time EPA believes that the economic impact of the construction requirements will be spread over at least a four-year period from the promulgation of the regulations because the regulations will not result in immediate compliance. The effective date of the regulations will be 18 months after promulgation. Non-compliance may not be discovered until initial sampling has been completed. For community water supplies the deadlines for initial sampling range from 1 day for turbidity to 2 years for inorganic samples of ground water systems after the effective date. Therefore, in some cases, more than 3 years from promulgation could elapse before inorganic violations would be detected and corrective actions initiated. In addition the use of the exemption or variance provisions of the regulations could further prolong compliance for public water systems unable to comply for economic or technical reasons.

It is estimated that the investor-owned water systems will pay approximately one-fourth of the total treatment costs, while the publicly-owned companies would pay the remainder. However, since many of the investor-owned systems serve very small populations, the capital demands on these systems could be great.

In 1974, the water supply industry spent approximately $1.5 billion for capital improvements. The average yearly total annual capital costs mandated by the Interim Primary Regulations are estimated to be about 13 to 24 percent of this figure. It is anticipated that the industry as a whole would be able to raise the additional necessary capital. Small systems could encounter difficulty in financing new treatment facilities, particularly when clarification, a relatively expensive treatment process, is required. The implementation of these Regulations may force many communities to allocate funds, which may be needed to provide other services to the community, for the treatment of their drinking water.

Data on non-community systems is sparse. However, it is not anticipated that these regulations will have a serious economic impact on them.

The macroeconomic effects of the Interim Primary Drinking Water Regulations are expected to be minimal. On the average, the regulations will cause an increase in water rates of 9.5 percent spread over several years. If this increase occurred in one year, the resulting increase in the Consumer Price Index (CPI) would be less than 0.001 percent. Since the costs of these regulations will be incurred over several years, the average annual increase in the CPI will be even less. The Chase Econometric model was used to examine the impact of all existing pollution abatement regulations.[1] The analysis showed that there will be an average annual increase in the CPI for 1974 to 1980 of less than 0.1 percent due to these pollution abatement regulations.

1.5 *Constraints to implementation of the interim primary drinking water regulations.* The implementation of the National Interim Primary Drinking Water Regulations within a reasonable time frame would greatly depend on the availability of key chemicals and supplies needed in the treatment of drinking water; availability of manpower to operate treatment facilities; adequate laboratory capability to conduct sample analyses; and sufficient supply of engineering and construction services to build or improve treatment facilities.

In particular, the Interim Regulations will increase demand for coagulants and disinfecting agents as the needed treatment facilities are completed. An increased demand could cause some temporary dislocations in chemical markets, but in the long-run, increased demand will result in an expansion of supplies. It is projected that the 1980 demand for ferric chloride may reach 115 to 120 percent of the present production, while alum demand will be approximately 115 percent of current production. There is a general consensus of opinion that organic polyelectrolytes will become the dominant flocculating agents in the future. However, there are no reliable estimates of which polyelectrolyte(s) will be dominant and when the shift in chemical usage will occur.

At the present time there are approximately 180,000 people employed in the water supply industry. With the implementation of the Interim Primary Drinking Water Regulations between 13,000 and 27,000 additional personnel would be needed nationwide. These personnel would be required to perform such tasks as monitoring and enforcing the Regulations, operating the required treatment facilities, performing laboratory analysis of water samples, program assistance and program administration. It is anticipated that water systems may have difficulty hiring qualified personnel.

The third potential constraint is in the availability of adequate laboratories to perform the required chemical and biological analyses. Coliform monitoring is now being performed at State, local and private laboratories. In meeting the coliform monitoring requirements, water suppliers should not have difficulty finding laboratory facilities. At the present time there is little routine monitoring being done for heavy metals and organic compounds of concern in the Regulations. However, there are adequate numbers of public and private laboratories capable of performing these analyses although State certification of laboratories, required by the regulations, could constrain available laboratory facilities.

The final area where constraints could occur is in the design and construction of the required treatment facilities. Although the annual cost of required new construction represents less than 0.4 percent of the present total annual new construction in the United States, design and construction of new water treatment plants is highly specialized. Some communities, especially those in rural areas, may have difficulty obtaining these services due to their expense or unavailability.

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[1] Chase Econometric Associates, Inc. "The Macroeconomic Impacts of Federal Pollution Control Programs," prepared for the Council of Environmental Quality and the Environmental Protection Agency, January 1975.

1.6 *Limits of the analysis*, In developing the cost estimates used in this study, it was necessary to use several simplifying assumptions. This section explores these assumptions and what their overall impact might be.

The first assumption is that there are 40,000 community water supply systems in the nation and that they are represented accurately by the current EPA inventory of community water supply systems. There is some evidence that when the inventory is completed there will be a total of 50,000 community systems rather than the estimated 40,000. This increase in systems would cause an increase in monitoring costs of about 12 percent and a similar increase in treatment costs.

All costs for public non-community systems were based on the assumption that there are 200,000 of these systems nationwide. At the present time there is no accurate inventory of these systems, thus, this number is solely an estimate. It is anticipated that the EPA will be performing an inventory of these systems in the next few years so that these estimates can be updated.

A major consideration not used in developing treatment costs is that many systems may use alternative water management practices rather than install more costly treatment processes when they exceed an MCL requirement. For example, ground water systems might blend water from a "clean" well with that from a "dirty" well so that the resultant water will not exceed the MCL. Similarly, no estimate is possible to determine the possible benefits which might result from cascading treatment processes. An example of this is that clarification units might remove enough heavy metals so that the MCL might not be exceeded. These treatment alternatives would vary from site to site so that it is impossible to quantify the benefits which would be derived.

1.7 *Energy use*. It is estimated that approximately 21,200 billion BTU's per year will be required to operate plants and produce chemicals for the various treatment systems necessary for the 40,000 community systems to meet the regulations. This is about 0.028 percent of the 1973 national energy consumption, based on the 1974 Statistical Abstract. The increase in energy use will depend on a number of factors, including whether pollution in surface sources of waters is successfully controlled. There will be no direct energy savings from the recommended action.

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PART 141—NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

Subpart E—Special Monitoring Regulations for Organic Chemicals

Pursuant to Sections 1445(a) and 1450(a)(1) of the Public Health Service Act, as amended by the Safe Drinking Water Act, Pub. L. 93–523, the Administrator of the Environmental Protection Agency hereby issues a new 40 CFR 141, Subpart E, to become effective immediately. This subpart establishes sampling, monitoring, testing and other requirements applicable to designated public water systems for the purpose of providing data for the establishment of maximum contaminant levels of organic contaminants in drinking water.

Concurrently with this publication, EPA is promulgating National Interim Primary Drinking Water Regulations under the authority of the Safe Drinking Water Act ("SDWA"). Those regulations contain maximum contaminant levels, monitoring frequencies and analytical procedures for microbiological contaminants, turbidity, and selected inorganic and organic chemicals. The Interim Primary Drinking Water Regulations are to become effective 18 months after promulgation.

EPA is embarking on an intensive research program to find answers to the following questions:

1. What are the effects of commonly occurring organic compounds on human health?

2. What analytical procedures should be used to monitor finished drinking water to assure that any Primary Drinking Water Regulations dealing with organics are met?

3. Because some of these organic compounds are formed during water treatment, what changes in treatment practices are required to minimize the formation of these compounds in treated water?

4. What treatment technology must be applied to reduce contaminant levels to concentrations that may be specified in the Primary Drinking Water Regulations?

This research will involve health-effects and epidemiological studies, investigations of analytical methodology, and pilot plant and field studies of organic removal unit processes. Some phases of the research are to be completed by the end of this year, while much of the remainder are to be completed within the next calendar year.

Subpart E is intended to provide a rapid means of obtaining data in support of the possible establishment of additional maximum contaminant levels for organic chemical contaminants of drinking water, either as individual compounds or groups of compounds. These regulations will form the basis of a wide-ranging monitoring and analytical study to be performed by EPA in conjunction with the States and designated participating public water systems. These regulations will also generate information on the occurrence of potentially hazardous organic chemicals in a cross-section of public water systems covering a substantial portion of the population of the United States and representing various types of drinking water sources and treatment processes. They will provide information which is currently lacking on the actual distribution of a number of organic chemicals and will make it possible for EPA to attempt to correlate the presence of these chemicals with the results of several general and chemical group analytical procedures. This information will aid in the development of future primary drinking water regulations.

The recently completed National Organics Reconnaissance Survey (NORS) reported detection of six volatile organic compounds in a sampling of 80 cities. Extensive additional gas chromatographic/mass spectrometric analyses were performed on 10 of these 80 water systems. However, these were one-time samples and therefore do not indicate seasonal effects on drinking water quality nor any other temporary factors such as intermittent discharge or the long term effects of treatment applications in controlling finished water quality. The special study covered by these regulations was derived, in part, from the preliminary results obtained in the NORS Survey and is intended to respond to many of the questions which it raised so that the appropriate regulatory actions may be determined. Many of the systems from the previous survey will be resampled several times during this period to provide an indication of longer-term and seasonal variations in the quality of drinking water.

This study will include analyses for approximately 20 specific organic compounds deemed to be candidates for particular concern, and analyses of 6 surrogate group chemical parameters which are indicators of the total amount of organic contamination. Several of these surrogate procedures show promise as indicators of specific families of compounds such as chlorinated (halogenated) organics or aromatic compounds. They also show promise as practical methods which could be developed and widely applied for surveillance and quality control of drinking water in many water systems, particularly those public water systems which are not large enough to be financially capable of providing highly sophisticated computerized gas chromatographic/mass spectrometric analyses.

In order to assure a rapid and efficient method of providing data of uniform and assured quality, EPA will assume the principal responsibility for analysis and evaluation of the water samples taken by the designated public water systems. The water systems involved may be required to provide background information and follow-up investigation as necessary.

EPA feels that this monitoring study, in conjunction with its other substantial research efforts, will provide the basis for a coherent and rational approach to the control of organic chemical contamination of public water systems.

Good cause exists for promulgation of these regulations without first asking for comment on them, in view of the widespread public concern, the need to move as quickly as possible to carry out the Congressional mandate to deal with organic chemicals, and in view of the fact that the burden imposed on designated public water systems is limited.

ORGANIC CHEMICALS TO BE SURVEYED

The basic monitoring study will be completed within one year and will involve multiple samplings from each designated system. Water samples and concentrates will be collected on site and shipped to EPA laboratories for analysis.

The study will consist of analyses for a number of organic compounds and 6 surrogates in approximately 100 public water systems in the United States. Many of the compounds to be selected for inclusion in this study will be halogenated and aromatic organic compounds. Virtually no chlorinated organic compounds are known to occur naturally in fresh water. Many are considered to be liver toxins and/or potential carcinogens in some concentration. It would be expected that any chlorinated organic compounds found in drinking water would have been generated either from industrial manufacturing operations, agricultural operations, or during chlorination of water for the purpose of disinfection. Many aromatic compounds are also considered to be chronic toxicants and some have been shown to be carcinogens in test systems such as animal feeding. Aromatic compounds might also reach drinking water systems from industrial sources, urban surface runoff, or from atmospheric fallout of materials generated during combustion processes. Other possible candidates include aromatic amines and nitrosamines.

The compounds to be studied are being selected on the basis of available toxicity data, information on possible occurrence in public water systems with significant frequency, and the availability of practical analytical methods for identification and quantification. They may include: benzene; carbon tetrachloride; p-dichlorobenzene; vinyl chloride; 1, 2, 4-trichlorobenzene; bis-(2-chloroethyl) ether; 1, 1, 2-trichloroethylene; 2, 4-dichlorophenol; fluoranthene; 11, 12-benzofluoranthene; 3, 4-benzofluoranthene; 1, 12-benzoperylene; 3, 4-benzopyrene; indeno (1, 2, 3-cd) pyrene; chloroform; bromodichloromethane; bromoform; 1, 2-dichloroethane; polychlorinated biphenyls; and pentachlorophenol. Additional studies will be performed on aromatic amines (e.g. benzidine) and nitrosamines.

In addition to the analyses of specific compounds, a number of analyses of general organic indicators will be performed in order to determine possible relationships between the presence of the specific chemicals and certain general surrogate analytic procedures which should be more applicable for routine monitoring in public water systems. The following general indicators will be used:

(1) Total Organic Carbon analysis offers promise as a general organic measurement parameter for drinking water and is already widely accepted in the area of waste treatment organics monitoring. The procedure indicates the total amount of organically bound carbon present in the sample and is not selective among types of compounds. The technique essentially consists of oxidation of the organic chemicals in a water sample to carbon dioxide which is either quantified directly or converted to methane which is then quantified. Sample collection is simple, analysis is rapid (10 minutes) and may be automated, cost per sample is low, and interference from inorganic carbon can be avoided. Reliable and accurate instrumentation is now becoming available for application of this procedure to drinking water.

(2) The Ultraviolet and Fluorescence Spectroscopic methods, which primarily indicate the presence of aromatic compounds. The advantages of these methods are sampling simplicity, the small sample size required, and the speed and low cost per sample.

(3) Color analyses, which are relatively simple and rapid methods which may indicate the presence of certain organic compound types, particularly humic substances. Some recent data indicate that a relatively quantitative relationship may exist between color intensity and the quantity of humic substances which represent the largest portion of dissolved organic chemicals in some waters.

(4) Total Organic Chlorine analyses, which offer promise for rapid, accurate indication of the presence of all chlorine-containing organic compounds. This procedure involves oxidation of the halo-organics in a water sample followed by microcoulometric quantification. The analysis is rapid after sample concentration. The present apparatus has not generally been applied to drinking water, but EPA is conducting a concurrent program to develop the application so that this potentially important method may be utilized in this monitoring study.

(5) The Carbon-Chloroform Extract procedure (CCE), which consists of passage of 60 liters of water through a carbon column at a constant rate for 48 hours. The carbon adsorbant is then extracted with refluxing chloroform followed by removal of most of the chloroform and evaporation of the residue to constant weight. The entire analytical process requires about 6 days for completion and the concentrates represent something less than 10% of the total organics content of the sampled water. Therefore, CCE is not amenable to on-line process control monitoring. However, in this study, this CCE data and historical CCE data will be interrelated with specific compound analyses and the other surrogate analyses, to designate the optimum monitoring methodologies for field use which are most indicative of the presence of those organic compounds which potentially pose risks to human health.

Other methods of sample collection and concentration which are being evaluated for this and concurrent studies include the use of macroreticular resins which have shown promise for application to drinking water analytical technology.

Within two weeks from the publication of this subpart, in consultation with the States, EPA will designate approximately 100 public water systems for inclusion in the special monitoring program for organic chemicals. The systems will be selected to represent each major type of water supply (rivers, impoundments and ground water), quality of water, treatment, region and population size. Most of the systems should serve large metropolitan areas, but some may be small enough to be representative of the water types and problems associated with smaller systems. The number of systems to be selected will be sufficient to permit an evaluation of the relationship of specific contaminant concentrations to several general organic parameters.

EPA in consultation with the State will work closely with each system to assure that proper sampling techniques are used. In addition, when preliminary results indicate that a potentially harmful organic chemical is present in significant amounts in a particular water system, EPA and the State will consult with the system and provide technical advice and assistance where appropriate. In some cases, it may be possible to identify a particular point source which is causing serious contamination of a public water system, or to determine that additional treatment should be installed by a system without waiting for the nationwide survey results.

For the reasons given above, Chapter 40 of the Code of Federal Regulations is hereby amended by adding Subpart E to Part 141, as follows. The new regulations take effect December 24, 1975.

Dated: December 10, 1975.

RUSSELL E. TRAIN,
Administrator.

§ 141.40 Special monitoring for organic chemicals.

(a) The Administrator may designate, by publication in the FEDERAL REGISTER, public water systems which are required to take water samples, provide information, and in appropriate cases analyze water samples for the purpose of providing information on contamination of drinking water sources and of treated water by organic chemicals.

(b) The Administrator shall provide to each public system designated pursuant to paragraph (a) of this section a written schedule for the sampling of source water or treated water by the system, with written instructions for the sampling methods and for handling of samples. The schedule may designate the locations or types of locations to be sampled.

(c) In cases where the public water system has a laboratory capable of analyzing samples for constituents specified by the Administrator, the Administrator may require analyses to be made by the public water system for submission to EPA. If the Administrator requires the analyses to be made by the public water system, he shall provide the system with written instructions as to the analytical procedures to be followed, or with references to technical documents describing the analytical procedures.

(d) Public water systems designated by the Administrator pursuant to paragraph (a) of this section shall provide to the Administrator, upon request, information to be used in the evaluation of analytical results, including records of previous monitoring and analyses, information on possible sources of contamination and treatment techniques used by the system.

(Secs. 1445 and 1450 of the Public Health Service Act, 88 Stat. 1660 (42 U.S.C. 300j-4 and 300j-9))

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FRIDAY, JULY 9, 1976

PART II:

ENVIRONMENTAL PROTECTION AGENCY

■

DRINKING WATER REGULATIONS

Radionuclides

Title 40—Protection of Environment

CHAPTER 1—ENVIRONMENTAL PROTECTION AGENCY

[FRL 552-2]

PART 141—INTERIM PRIMARY DRINKING WATER REGULATIONS

Promulgation of Regulations on Radionuclides

On August 14, 1975, the Environmental Protection Agency (EPA) proposed national interim primary drinking water regulations for radioactivity pursuant to sections 1412, 1445, and 1450 of the Public Health Service Act ("the Act"), as amended by the Safe Drinking Water Act, Pub. L. 93-523, 40 FR 34324. Numerous written comments on the proposed regulations were received, and a public hearing was held in Washington on September 10, 1975.

The regulations for radioactivity are hereby promulgated in final form. A number of changes have been made in the proposed regulations in response to comments received. These changes represent efforts to clarify what are necessarily technical and complex provisions and to make monitoring requirements more realistic. The proposed maximum contaminant levels for radionuclides have been retained as proposed.

The comments received on the proposed regulations and EPA's response to those comments are discussed in detail in Appendix A. The promulgated radionuclides regulations and Appendix A should be read in the context of the national interim primary drinking water regulations as a whole. The regulations concerning microbiological, chemical and physical maximum contaminant levels, and related regulations dealing with public notification of violations and reports and record-keeping by public water systems, were promulgated on December 24, 1975, 40 FR 59566.

The balance of this preamble discusses briefly the five major issues highlighted in the preamble to the proposed radionuclides regulations, and lists in summary form the changes made in the proposed regulations.

The preamble of the proposed regulations listed five issues on which comment was particularly requested:

1. The number and location of the public water systems impacted by the proposed maximum contaminant levels for radionuclides.
2. The number and location of water supplies requiring radium analysis at the proposed 2 pCi/liter gross-alpha-particle-activity screening level.
3. The estimated preliminary assessments of the costs and technology for radium removal.
4. The validity and appropriateness of an aggregate dose method for setting maximum contaminant levels.
5. The acceptability of a maximum contaminant level for radium of 5 pCi/liter as opposed to a higher or lower level.

Public Water Systems Impacted: Little significant information was provided with respect to the number of community water systems that may exceed the proposed maximum contaminant levels. The State of Texas did report that 15 community water systems in that State would exceed the 5 pCi limit for radium: EPA estimated in the preamble to the proposed regulations that a total of approximately 500 of the Nation's community water systems would exceed the proposed radium limit. It is likely that relatively few community water systems currently exceed the proposed maximum contaminant levels for either gross alpha particle activity or man-made radioactivity. Those levels are intended as preventative limits rather than as corrective limits.

Public Water Systems Requiring Radium Analysis: The monitoring requirements for the radium maximum contaminant level provide for an initial screening measurement of gross alpha particle activity to determine if analysis for radium-226 is needed. EPA requested comment on the number and location of community water systems that would exceed the proposed screening level of 2 pCi/l. A number of comments were received on the possible impact of the proposed screening level. The principal concern expressed was that a 2 pCi/liter screening level was unnecessarily low and would force a large number of public water systems to conduct expensive radium analyses in cases where the radium limit was not being exceeded.

A number of commentors were under the impression that radium daughter products were in equilibrium with radium in drinking water so that their accompanying alpha particle activity would be an indication of radium. Monitoring data from many public water systems indicates that because of differences in solubility and geological processes, the alpha particle activity is frequently much lower than would be observed for an equilibrium mixture of radium and daughter products and sometimes may be no greater than that due to radium-226 alone.

EPA agrees that in many cases adequate protection can be obtained with a screening level higher than 2 pCi/liter provided that the precision of the measurement is great enough to insure that the gross alpha activity is unlikely to exceed 5 pCi/l. The regulations have been amended accordingly. The effect of this change is that a screening test, in lieu of radium analysis, is permitted for most systems having gross alpha particle activities as high as 4 pCi/l. However, as noted in the Statement of Basis and Purpose for the proposed radionuclide regulations, care should be taken in evaluating the results of the screening test because the alpha particle activity screen does not measure radium-228, a beta emitter. For this reason, EPA recommends that, in localities where radium-228 may be present in significant quantities, the State establish a screening level no greater than 2 pCi/liter.

Costs and Technology for Radium Removal: One comment on radium removal costs stated that the EPA cost estimates may be too high because new technologies for radium removal are being developed. Another comment stated that the EPA estimates appear "reasonable at this time," and a third that the estimates are "too general" in that system size was not considered.

As discussed in the Statement of Basis and Purpose for the proposed radionuclides regulations, costs for radium removal were found to be essentially independent of system size for systems treating less than three million gallons per day. Since there are no data indicating that the maximum contaminant level for radium is being exceeded in systems larger than this, the EPA cost estimates are valid.

Three commentors thought the cost projections for radium removal might be low because disposal of radium wastes was not considered. The Agency is presently conducting a research study to investigate disposal costs. Compared to industrial effluents containing radium, the amount of radium involved is quite small. The only available data indicate that a commercial waste disposal service for radioactive materials would be expected to cost about 50 cents annually per person served for radium disposal. However, costs will vary depending on locality and the disposal method used. It should also be noted that any radium disposal problems generated by the proposed regulations will not be unlike those already encountered by the many communities already removing radium as part of their water softening processing.

Other comments suggested consideration of occupational exposure to radium in water treatment plants. The Agency has made a limited examination of the levels of radiation in the vicinity of ion exchange units used to remove radium in operating water treatment plants. Exposure levels to operating personnel are measurable and occupational exposures could range up to 25–100 mrem/yr. These doses are well below the Federal occupational guides for radiation workers of 5000 mrem/yr. Appropriate Federal Radiation Guidance will be provided if future studies indicate the problem of occupational exposure to treatment plant personnel is serious.

One commentor questioned the efficiency of radium removal by ion exchange used in the cost analysis in Appendix V of the Statement of Basis and Purpose. That analysis shows that treatment cost is relatively independent of radium removal efficiency as long as removal exceeds 90 percent. Operating data from currently used municipal water treatment systems indicate that average radium removal efficiency throughout the exchange cycle ranges from 93 to 97 percent.

Aggregate Dose Level: As noted in the preamble to the proposed radionuclides regulations, 40 FR 34325, EPA considered but rejected the use of an aggregate dose level in establishing maximum contaminant levels. This approach would consider both the risk to individuals and the total risk to the population served, so that the maximum contaminant level would be inversely related, within limits, to the size of the exposed population group. Comments on the concept of aggregate dose levels overwhelmingly endorsed EPA's decision not to use that approach in the development of maximum levels under the Safe Drinking Water Act.

Maximum Contaminant Level for Radium: A number of States submitted comments on EPA's proposal to establish the maximum contaminant level for radium at 5 pCI/liter. One State suggested that a limit of 10 pCI/liter be established for small public water systems. This suggestion has not been accepted by EPA because the legislative history of the Safe Drinking Water Act indicates that, to the extent possible, all persons served by public water systems should be protected by the same maximum contaminant levels. A number of other States expressed concurrence in the 5 pCi/liter limit.

One commentor cited the results of a U.S. Public Health Service study that indicated that persons in communities with water having a concentration of 4.7 pCi/liter had a higher mortality incidence due to bone sarcoma than persons in communities with water having less than 1 pCi/liter. The commentor contended that the USPHS study did not show a significant difference in cancer risk at a 95 percent confidence level, and that in any event the number of excess cancers was significantly less than would be predicted on the basis of the NAS–BEIR Report.

EPA notes that the confidence level of the USPHS study was 92 percent which is not significantly different from a 95 percent criterion considering the overall precision of the USPHS study. Mortality estimates on which the 5 pCi/liter limit was based included all cancers, not just bone sarcoma. Moreover, the EPA estimates are for lifetime exposures, whereas most of the participants in the USPHS study were exposed for a substantially shorter period of time. Moreover, the incidence of cancer observed in the USPHS study is somewhat greater than would be predicted by the linear dose response model used by EPA, not less as suggested by the commentor. Given these facts it is EPA's view that the USPHS study supports its use of risk estimates from ingested radium as a valid measure of the impact of various control levels. EPA will, however, study new cancer incidence data as they become available to determine whether the 5 pCi/liter level provides appropriate protection.

Changes Made in the Proposed Regulations:

In response to comments received on the proposed regulations, a number of changes have been made. The comments and changes are discussed in some detail in Appendix A. The following list summarizes changes which have been made:

1. Section 141.2 has been revised to simplify the definitions of "gross alpha particle activity" and "gross beta particle activity." As proposed these definitions were confusing because they sought to make distinctions which were more properly set forth in §§ 141.15 and 141.16.

2. Section 141.15 has been changed to make clear that the maximum contaminant level for gross alpha particle activity does not apply to isotopes of uranium and radon.

3. Section 141.16 has been redrafted for clarity and provisions relating to the means of determining compliance have been moved to § 141.26. It should be noted that the average annual concentration of strontium-90 yielding 4 mrem per year to bone marrow is 8 pCi/1 not 2 pCi/1 as was stated in the Proposed Regulations. Accordingly, Table A in Section 141.16 has been corrected and the detection limit for strontium-90 listed in Table B, § 141.25 has been changed to 2pCi/1.

4. Section 141.25 has been revised to include newer analytical methods and to delete some obsolescent methods. The definition of detection limit has been changed to indicate clearly that it applies only to uncertainty in the precision of the measurement due to counting errors. Also, a new detection limit of 4 pCi/liter has been established for gross beta particle activity so that gross beta analysis may be substituted for strontium-89 and cesium-134 analyses in some cases. It should be noted that under. § 141.27 the State, with the concurrence of the Administrator, may authorize the use of alternative analytical methods having the same precision and accuracy as those listed in §§ 141.25 and 141.26.

5. Section 141.26 has been redrafted for clarity and the alpha particle activity screening level has been redefined to provide a higher gross alpha screening limit as long as the precision of measurement insures that the gross alpha activity is unlikely to exceed 5 pCi/1. Also, the requirement for quarterly sampling has been revised to permit a yearly sample where a one-year record based on quarterly sampling has indicated the average annual gross alpha particle activity and radium-226 activity to be less than half the applicable maximum contaminant level. The period allowed for initial monitoring has been extended to three years rather than two years after the effective date of these regulations. Also, rather than require that subsequent monitoring be every three years for ground water and every five years for surface water, monitoring for both ground water and surface water will be required every four years.

6. Section 141.26 has been amended to provide that, when ordered by the State, a community water system will be required to participate in a watershed monitoring program for man-made radioactivity. EPA recommends that States require such programs in each principal watershed under their jurisdiction. In addition, the provision allowing the use of discharge data from nuclear facilities in lieu of special monitoring for man-made radioactivity has been amended to allow only the use of environmental surveillance data taken in conjunction with the State. Also in § 141.26 a screening level for gross beta particle activity has been established to reduce the cost of monitoring water systems affected by nuclear facilities.

If any screening levels for gross beta particle activity are exceeded, identification of specific radionuclides is mandatory prior to public notification and initiation of any enforcement action. In addition to the gross beta particle activity measurement, it may be necessary, as new energy technologies become available in the future, to monitor for specific man-made contaminants other than those currently identified. The Act provides that these regulations may be amended from time to time.

EFFECTIVE DATE

Section 1412(a)(3) of the Act provides that "The interim primary regulations first promulgated * * * shall take effect eighteen months after the date of their promulgation." The interim primary regulations first promulgated were those for microbiological, chemical and physical contaminants. They were promulgated on December 24, 1975, and will become effective June 24, 1977. Because it is desirable that all of the basic interim primary drinking water regulations take effect on the same date, and in view of the long lead time provided to public water systems for compliance with these radionuclide regulations, the radionuclide regulations also will become effective on June 24, 1977.

It is hereby certified that the economic and inflationary impacts of these regulations have been carefully evaluated in accordance with Executive Order 11821, and it has been determined that an Inflation Impact Statement is not required. (The estimated ten million dollar annual cost is less than the one-hundred million dollar annual cost cut-off established as the minimum for which an Inflation Impact Statement is required.)

For the reasons given above, Part 141, Chapter 40 of the Code of Federal Regulations is hereby amended as follows:

RUSSELL TRAIN,
Administrator.

JUNE 28, 1976.

1. By revising § 141.2 to include the following new paragraphs (j) through (o):

§ 141.2 Definitions.

* * * * *

(j) "Dose equivalent" means the product of the absorbed dose from ionizing radiation and such factors as account for differences in biological effectiveness due to the type of radiation and its distribution in the body as specified by the International Commission on Radiological Units and Measurements (ICRU).

(k) "Rem" means the unit of dose equivalent from ionizing radiation to the total body or any internal organ or organ system. A "millirem (mrem)" is 1/1000 of a rem.

(l) "Picocurie (pCi)" means that quantity of radioactive material producing 2.22 nuclear transformations per minute.

(m) "Gross alpha particle activity" means the total radioactivity due to alpha particle emission as inferred from measurements on a dry sample.

(n) "Man-made beta particle and photon emitters" means all radionuclides emitting beta particles and/or photons listed in Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure, NBS Handbook 69, except the daughter products of thorium-232, uranium-235 and uranium-238.

(o) "Gross beta particle activity" means the total radioactivity due to beta particle emission as inferred from measurements on a dry sample.

2. By adding §§ 141.15, 141.16, 141.25 and 141.26 as follows:

§ 141.15 Maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity in community water systems.

The following are the maximum contaminant levels for radium-226, radium-228, and gross alpha particle radioactivity:

(a) Combined radium-226 and radium-228—5 pCi/1.

(b) Gross alpha particle activity (including radium-226 but excluding radon and uranium)—15 pCi/1.

§ 141.16 Maximum contaminant levels for beta particle and photon radioactivity from man-made radionuclides in community water systems.

(a) The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year.

(b) Except for the radionuclides listed in Table A, the concentration of man-made radionuclides causing 4 mrem total body or organ dose equivalents shall be calculated on the basis of a 2 liter per day drinking water intake using the 168 hour data listed in *"Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air or Water for Occupational Exposure,"* NBS Handbook 69 as amended August 1963, U.S. Department of Commerce. If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 millirem/year.

TABLE A.—*Average annual concentrations assumed to produce a total body or organ dose of 4 mrem/yr*

Radionuclide	Critical organ	pCi per liter
Tritium	Total body	20,000
Strontium-90	Bone marrow	8

§ 141.25 Analytical Methods for Radioactivity.

(a) The methods specified in *Interim Radiochemical Methodology for Drinking Water,* Environmental Monitoring and Support Laboratory, EPA-600/4-75-008, USEPA, Cincinnati, Ohio 45268, or those listed below, are to be used to determine compliance with §§ 141.15 and 141.16 (radioactivity) except in cases where alternative methods have been approved in accordance with § 141.27.

(1) Gross Alpha and Beta—Method 302 "Gross Alpha and Beta Radioactivity in Water" *Standard Methods for the Examination of Water and Wastewater,* 13th Edition, American Public Health Association, New York, N.Y., 1971.

(2) Total Radium—Method 304 "Radium in Water by Precipitation" Ibid.

(3) Radium-226—Method 305 "Radium-226 by Radon in Water" Ibid.

(4) Strontium-89,90 — Method 303 "Total Strontium and Strontium-90 in Water" Ibid.

(5) Tritium—Method 306 "Tritium in Water" Ibid.

(6) Cesium-134 — ASTM D-2459 "Gamma Spectrometry in Water," *1975 Annual Book of ASTM Standards, Water and Atmospheric Analysis,* Part 31, American Society for Testing and Materials, Philadelphia, PA. (1975).

(7) Uranium—ASTM D-2907 "Microquantities of Uranium in Water by Fluorometry," Ibid.

(b) When the identification and measurement of radionuclides other than those listed in paragraph (a) is required, the following references are to be used, except in cases where alternative methods have been approved in accordance with § 141.27.

(1) *Procedures for Radiochemical Analysis of Nuclear Reactor Aqueous Solutions,* H. L. Krieger and S. Gold, EPA-R4-73-014. USEPA, Cincinnati, Ohio, May 1973.

(2) *HASL Procedure Manual,* Edited by John H. Harley. HASL 300, ERDA Health and Safety Laboratory, New York, N.Y., 1973.

(c) For the purpose of monitoring radioactivity concentrations in drinking water, the required sensitivity of the radioanalysis is defined in terms of a detection limit. The detection limit shall be that concentration which can be counted with a precision of plus or minus 100 percent at the 95 percent confidence level (1.96σ where σ is the standard deviation of the net counting rate of the sample).

(1) To determine compliance with § 141.15 (a) the detection limit shall not exceed 1 pCi/l. To determine compliance with § 141.15(b) the detection limit shall not exceed 3 pCi/l.

(2) To determine compliance with § 141.16 the detection limits shall not exceed the concentrations listed in Table B.

TABLE B.—DETECTION LIMITS FOR MAN-MADE BETA PARTICLE AND PHOTON EMITTERS

Radionuclide	*Detection limit*
Tritium	1,000 pCi/l.
Strontium-89	10 pCi/l.
Strontium-90	2 pCi/l.
Iodine-131	1 pCi/l.
Cesium-134	10 pCi/l.
Gross beta	4 pCi/l.
Other radionuclides	1/10 of the applicable limit.

(d) To judge compliance with the maximum contaminant levels listed in sections 141.15 and 141.16, averages of data shall be used and shall be rounded to the same number of significant figures as the maximum contaminant level for the substance in question.

§ 141.26 Monitoring Frequency for Radioactivity in Community Water Systems.

(a) Monitoring requirements for gross alpha particle activity, radium-226 and radium-228.

(1) Initial sampling to determine compliance with § 141.15 shall begin within two years of the effective date of these regulations and the analysis shall be completed within three years of the effective date of these regulations. Compliance shall be based on the analysis of an annual composite of four consecutive quarterly samples or the average of the analyses of four samples obtained at quarterly intervals.

(i) A gross alpha particle activity measurement may be substituted for the required radium-226 and radium-228 analysis *Provided,* That the measured gross alpha particle activity does not exceed 5 pCi/l at a confidence level of 95 percent (1.65σ where σ is the standard deviation of the net counting rate of the sample). In localities where radium-228 may be present in drinking water, it is recommended that the State require radium-226 and/or radium-228 analyses when the gross alpha particle activity exceeds 2 pCi/1.

(ii) When the gross alpha particle activity exceeds 5 pCi/1, the same or an equivalent sample shall be analyzed for radium-226. If the concentration of radium-226 exceeds 3 pCi/1 the same or an equivalent sample shall be analyzed for radium-228.

(2) For the initial analysis required by paragraph (a)(1), data acquired within one year prior to the effective date of this part may be substituted at the discretion of the State.

(3) Suppliers of water shall monitor at least once every four years following the procedure required by paragraph (a)(1). At the discretion of the State, when an annual record taken in conformance with paragraph (a)(1) has established that the average annual concentration is less than half the maximum contaminant levels established by § 141.15, analysis of a single sample may be substituted for the quarterly sampling procedure required by paragraph (a)(1).

(i) More frequent monitoring shall be conducted when ordered by the State in the vicinity of mining or other operations which may contribute alpha particle radioactivity to either surface or ground water sources of drinking water.

(ii) A supplier of water shall monitor in conformance with paragraph (a)(1) within one year of the introduction of a new water source for a community water system. More frequent monitoring shall be conducted when ordered by the State in the event of possible contamination or when changes in the distribution system or treatment processing occur which may increase the concentration of radioactivity in finished water.

(iii) A community water system using two or more sources having different concentrations of radioactivity shall monitor source water, in addition to water from a free-flowing tap, when ordered by the State.

(iv) Monitoring for compliance with § 141.15 after the initial period need not include radium-228 *except when* required by the State, *Provided*, That the average annual concentration of radium-228 has been assayed at least once using the quarterly sampling procedure required by paragraph (a)(1).

(v) Suppliers of water shall conduct annual monitoring of any community water system in which the radium-226 concentration exceeds 3 pCi/1, when ordered by the State.

(4) If the average annual maximum contaminant level for gross alpha particle activity or total radium as set forth in § 141.15 is exceeded, the supplier of a community water system shall give notice to the State pursuant to § 141.31 and notify the public as required by § 141.32. Monitoring at quarterly intervals shall be continued until the annual average concentration no longer exceeds the maximum contaminant level or until a monitoring schedule as a condition to a variance, exemption or enforcement action shall become effective.

(b) Monitoring requirements for man-made radioactivity in community water systems.

(1) Within two years of the effective date of this part, systems using surface water sources and serving more than 100,000 persons and such other community water systems as are designated by the State shall be monitored for compliance with § 141.16 by analysis of a composite of four consecutive quarterly samples or analysis of four quarterly samples. Compliance with § 141.16 may be assumed without further analysis if the average annual concentration of gross beta particle activity is less than 50 pCi/1 and if the average annual concentrations of tritium and strontium-90 are less than those listed in Table A, *Provided*, That if both radionuclides are present the sum of their annual dose equivalents to bone marrow shall not exceed 4 millirem/year.

(i) If the gross beta particle activity exceeds 50 pCi/1, an analysis of the sample must be performed to identify the major radioactive constituents present and the appropriate organ and total body doses shall be calculated to determine compliance with § 141.16.

(ii) Suppliers of water shall conduct additional monitoring, as ordered by the State, to determine the concentration of man-made radioactivity in principal watersheds designated by the State.

(iii) At the discretion of the State, suppliers of water utilizing only ground waters may be required to monitor for man-made radioactivity.

(2) For the initial analysis required by paragraph (b)(1) data acquired within one year prior to the effective date of this part may be substituted at the discretion of the State.

(3) After the initial analysis required by paragraph (b)(1) suppliers of water shall monitor at least every four years following the procedure given in paragraph (b)(1).

(4) Within two years of the effective date of these regulations the supplier of any community water system designated by the State as utilizing waters contaminated by effluents from nuclear facilities shall initiate quarterly monitoring for gross beta particle and iodine-131 radioactivity and annual monitoring for strontium-90 and tritium.

(i) Quarterly monitoring for gross beta particle activity shall be based on the analysis of monthly samples or the analysis of a composite of three monthly samples. The former is recommended. If the gross beta particle activity in a sample exceeds 15 pCi/1, the same or an equivalent sample shall be analyzed for strontium-89 and cesium-134. If the gross beta particle activity exceeds 50 pCi/1, an analysis of the sample must be performed to identify the major radioactive constituents present and the appropriate organ and total body doses shall be calculated to determine compliance with § 141.16.

(ii) For iodine-131, a composite of five consecutive daily samples shall be analyzed once each quarter. As ordered by the State, more frequent monitoring shall be conducted when iodine-131 is identified in the finished water.

(iii) Annual monitoring for strontium-90 and tritium shall be conducted by means of the analysis of a composite of four consecutive quarterly samples or analysis of four quarterly samples. The latter procedure is recommended.

(iv) The State may allow the substitution of environmental surveillance data taken in conjunction with a nuclear facility for direct monitoring of man-made radioactivity by the supplier of water where the State determines such data is applicable to a particular community water system.

(5) If the average annual maximum contaminant level for man-made radioactivity set forth in § 141.16 is exceeded, the operator of a community water system shall give notice to the State pursuant to § 141.31 and to the public as required by § 141.32. Monitoring at monthly intervals shall be continued until the concentration no longer exceeds the maximum contaminant level or until a monitoring schedule as a condition to a variance, exemption or enforcement action shall become effective.

APPENDIX A

RESPONSE TO PUBLIC COMMENTS

Proposed National Interim Primary Drinking Water Regulations for radionuclides, 40 FR 34324, were published for comment on August 14, 1975. Written comments on the proposed regulations were received, and a public hearing on the proposal was held in Washington on September 10, 1975. As a result of review of the written comments and of testimony at the public hearing, as well as further consideration of the available data by EPA, a number of changes have been made in the proposed regulations. The principal changes are summarized in the Preamble to the final regulations. The purpose of this Appendix is to discuss the comments received on various aspects of the proposed regulations, and to explain EPA's response to those comments.

Part I of the Appendix deals with comments on specific provisions of the proposed regulations, in numerical order. Part II concerns more general comments received by EPA. Responses to the five specific issues on which comments were solicited in the August 14 proposal are reviewed and discussed in the preamble to the promulgated regulations. Part III is the Agency's policy Statement of March 3, 1975, on the Relationship between radiation dose and effect.

PART I

Comments on Specific Provisions of the Proposed Regulations § 141.2—Definitions

A number of commentors stated that the definitions given in § 141.2 for gross beta particle and gross alpha particle activity were confusing because they excluded certain radionuclides. These definitions have been redrafted to omit the exclusions, which are more properly dealt with in the basic regulations.

§ 141.15—MAXIMUM CONTAMINANT LEVELS OF RADIUM-226, RADIUM-228, AND GROSS ALPHA PARTICLE RADIOACTIVITY

Several comments suggested that the maximum contaminant level for gross alpha particle activity should state clearly that this limit does not apply to isotopes of uranium and radon. This was the intention of the proposed regulations, and § 141.15 has been redrafted accordingly. Some commentors requested clarification of the impact of the exclusion of uranium and radon on monitoring procedures and compliance. It is true that the sample preparation techniques specified in § 141.25 preclude the measurement of the gaseous radionuclides radon-220 and radon-222. Their daughter products, however, will be retained in the sample as intended by these regulations. As noted in the Statement of Basis and Purpose, one of the main intentions of the maximum contaminant level for gross alpha particle activity is to limit the concentration of long half-life radium daughters. In cases where gross alpha particle activity exceeds 15 pCi per liter, analysis of the water for its uranium content by chemical or other means will be needed to determine compliance. Except in ground water impacted by uranium-bearing ores, such analyses will rarely be necessary.

Two commentors mentioned that no rationale for the gross alpha particle maximum contaminant limit of 15 pCi/1 was given in the preamble to the proposed regulations. The rationale for this limit is, however, discussed in the Statement of Basis and Purpose. It is based on a consideration of the radiotoxicity of other alpha particle emitting contaminants relative to radium. The 15 pCi/1 gross alpha particle limit, which includes radium-226 (but not uranium or radon), is based on the conservative assumption that if the radium concentration is 5 pCi/1 and the balance of the alpha particle activity is due to the next most radiotoxic alpha particle emitting chain starting with lead-210, the dose to bone will not be unduly increased. Though less precise than setting maximum contaminant levels for lead-210 specifically, the establishment of a limit on gross alpha particle activity is more in keeping with the current capability of State laboratories while providing significant public health protection. Reasons for omitting uranium and radon from the limit for gross alpha particle activity are given in the Statement of Basis and Purpose.

§141.16—MAXIMUM CONTAMINANT LEVELS OF BETA PARTICLE AND PHOTON RADIOACTIVITY FROM MAN-MADE RADIONUCLIDES

Several commentors had difficulty interpreting this section. It has been redrafted and that portion of the proposed maximum contaminant level for man-made radioactivity dealing with compliance has been moved to § 141.26 for purposes of clarity.

One commentor questioned the basis of the selection of the proposed 4 millirem annual limit. As stated in the preamble to the proposed regulations, the four millirem per year limit for man-made radioactivity was chosen on the basis of avoiding undesirable future contamination of public water supplies as a result of controllable human activities. Current levels of radioactivity in public water systems are below the proposed limit. Appropriate data on this point is provided in the Statement of Basis and Purpose.

Reference was made by one commentor to the Nuclear Regulatory Commission design criteria for light water reactors which limits the thyroid dose from a single nuclear reactor due to the liquid pathway to ten millirem per year. The commentor suggested that this number is in conflict with the proposed maximum contaminant level for man-made radioactivity. However, because the two levels are computed on different bases, iodine-131 concentrations meeting NRC design criteria would also meet maximum contaminant limits. Therefore, there is no conflict between these regulations and NRC design criteria. It should be noted, however, that the NRC limits are design criteria, not operational limits, and apply to only a single nuclear reactor. The EPA maximum contaminant limits have a completely different application. They apply to the finished waters served by a community water system which may use source waters contaminated by several reactors or other nuclear facilities.

Another commentor stated that the strontium-90 maximum contaminant level would produce a bone cancer dose of 4 millirem per year only after several decades of intake. That is correct—all of the maximum contaminant levels are based on an assumed lifetime ingestion at the concentration limits.

A few commentors stated that because in some localities the dose from strontium-90 in milk exceeds 4 mrem per year, the maximum contaminant level for strontium-90 in drinking water should be eliminated or made greater. The Administrator does not agree that the radioactive contamination of milk and milk products, which may occur in some localities, is a proper basis for relaxing maximum contaminant levels for drinking water. The maximum contaminant level for strontium-90 is not exceeded in community water systems at present nor is it likely to be exceeded in the foreseeable future. To permit unnecessary contamination of public water systems because of other environmental pathways impacting on man would be inappropriate.

A few commentors suggested that 2 liters per day was not an appropriate ingestion rate assumption for drinking water. The Administrator notes that a 2 liter per day intake is assumed for establishing maximum contaminant levels for all contaminants, not just radioactivity, and that this question has been discussed at length in the preamble and Appendix A to the National Interim Primary Drinking Water Regulations, 40 FR 59575.

A few commentors asked why potassium-40 was not considered as part of the maximum contaminant level for beta particle radioactivity. The amount of potassium in the body is controlled homostatically and is not proportional to water intake levels. Without the exception for potassium-40, some communities might be required to perform more analytical examination than necessary if waters exceeded the gross beta activity screening level. If the increased beta activity is due to potassium-40, there is no increased risk to users of the public water systems and therefore such tests are unnecessary.

§ 141.25—ANALYTICAL METHODS FOR RADIOACTIVITY

Several commentors noted that the Proposed Regulations on analytical methods did not allow for the substitution of equivalent alternative techniques. EPA agrees that this is an important consideration and § 141.27 has been added to the regulations to allow substitution of equivalent analytical methods with the approval of the State and the Administrator. Two commentors believed that no analytical methods should be specified as part of the regulations, 40 FR 34324. The Administrator believes, however, that defined analytical methods must be a part of the regulations so that compliance procedures are uniform and subject to verification.

Many commentors believed that alternative analytical methods were preferable to those listed in the proposed regulations and several made specific suggestions. EPA recognizes that some of the proposed analytical methods were obsolescent and for this reason a new handbook, *Interim Radiochemical Methodology for Drinking Water*, has been prepared by the Agency. § 141.25 has been revised to include these new methods and to delete some of the analytical methods proposed earlier. However, some Standard Methods have been retained because they are equivalent to the newer procedures and are currently being used by State laboratories.

Several comments concerned the need for laboratory certification and quality assurance. EPA will seek to certify at least one State laboratory in each State. The State may in turn certify additional laboratories. Pursuant to § 141.28, only monitoring results from laboratories approved or certified by the entity with primary enforcement responsibility will be acceptable.

Several comments were received concerning application of the defined detection limits. The detection limit requirements have been changed to indicate clearly that the limit applies only to uncertainty in the precision of the measurement due to counting errors. Other sources of imprecision and the overall accuracy of the determination are not a part of the detection limits given in this section but rather their control is to be implemented by means of the quality assurance program mentioned previously.

A few commentors believed that the proposed detection limit for gross alpha particle activity was too low. Because systems using very hard water may be unable to detect alpha particle activity at the 1 pCi/1 concentration, the detection limit for compliance with the gross alpha particle activity limit, § 141.15(b) has been increased to 3 pCi/1. This higher detection limit is not acceptable for gross alpha particle measurements substituted for radium analysis under § 141.26(a)(1)(i). If water hardness precludes use of this screening test, a radium analysis must be made to demonstrate compliance with § 141.15(1) of these regulations.

Most commentors believed the detection limits for man-made radioactivity were low but practicable in laboratories where modern testing facilities are available.

§ 141.26—MONITORING REQUIREMENTS FOR ALPHA PARTICLE AND RADIUM ACTIVITY

The major comments on § 141.26(a) were that the requirements were not clearly written and that the alpha particle activity screening test for a mandatory radium-226 measurement was too low thus necessitating unnecessary expense without increasing protection to the public health. Paragraph (a) has been redrafted to clarify the intent of these regulations; and, as discussed in the preamble to these regulations, the gross alpha particle screening level has been increased.

Some commentors objected to the requirement that quartely monitoring be continued when maximum contaminant levels are exceeded and others asked why quarterly sampling is needed. The reason why quarterly monitoring may provide additional public health protection where maximum contaminant levels are exceeded is discussed in the Statement of Basis and Purpose. The Agency agrees that quarterly sampling may be unnecessary in some cases and has amended the regulations to allow a single yearly sample where a one year historical record based on quarterly sampling shows the average annual gross alpha particle activity and the radium-226 activity to be less than one-half the applicable maximum contaminant levels.

Comments were divided on sampling frequency. Citizen groups tended to want more frequent monitoring and the States less frequent monitoring. Of particular public interest was the possible contamination of ground and surface water by mining operations. The revised regulations encourage the State to require more frequent monitoring for natural radioactivity in situations where mining or other operations may impact on water quality, when new sources of supply water are utilized or when water treatment processing is changed by the supplier of a community water system.

Several commentors requested an extension of the initial two-year period proposed for mandatory compliance. EPA is aware that these regulations call for a more expanded monitoring effort than is presently being carried out by most States. The regulations have been revised to require that initial monitoring begin within two years and that analysis be completed within three years of the effective date. In addition, the Agency has reconsidered, as suggested by several commentors, the proposed requirement that ground water be monitored every three years and surface water every five years and believes monitoring every four years for each is appropriate. The regulation has been so amended.

A few States requested that the initial monitoring of any community water system for radioactivity be at the discretion of the State and that the frequency of monitoring be determined by each State on a case by case basis. This is essentially the system now used. Congress has mandated *improved* control of drinking water quality, and these regulations seek to carry out that mandate.

Two commentors objected to the Agency's use of a gross alpha screening test to determine the need for radium-226 measurements because such a test is not applicable to radium-228, a beta emitter. Since radium-226 and radium-228 are not part of the same decay series, one of the commentors believed an evaluation which measures only gross alpha particle activity was inappropriate. It is true that radium-228 and radium-226 are in different decay series. However, the available monitoring data indicate that there is no record of radium-228 occurring in community water systems unless it is accompanied by radium-226. As pointed out in the Statement of Basis and Purpose, the radium-226 concentration in public water supply systems is almost always greater than the radium-228 concentration. Therefore, a screening test based on gross alpha particle activity is valuable for determining when further testing for specific radionuclides is necessary. However, States are encouraged to require specific analyses for both radium-226 and radium-228 where radium-228 may be present.

Several commentors raised questions concerning the points at which samples are to be taken and the procedure to be followed where multiple, or alternate, sources are utilized. As indicated in both the Statement of Basis and Purpose, and § 141.2(c) of the Interim Primary Drinking Water Regulations, sampling is to be done at the "free-flowing outlet of the ultimate user." Where multiple sources are employed, the samples should represent an unbiased estimate of the maximum concentration of radionuclides ingested by persons served by the system.

The Administrator recognizes that in some communities several wells are used at different periods throughout the year to supply drinking water and that because of different concentrations of radioactivity in these wells the concentration in finished water may fluctuate considerably. It is recommended that in such cases the States require augmented sampling programs which include monitoring of source waters. In the revised regulations the State has been given authority to order such monitoring.

§ 141.26(b)—MONITORING REQUIREMENTS FOR MAN-MADE RADIOACTIVITY

There were two types of objection to the proposal that mandatory monitoring for man-made radioactivity be confined to systems serving more than 100,000 persons and systems impacted by nuclear facilities. Some commentors felt that all systems, including those utilizing ground water, should be monitored. Others believed that monitoring only systems serving large communities would not adequately reflect the situation in their States.

EPA believes that because of cost and the size and number of laboratories available now to do the radiochemical analysis required for man-made radioactivity, monitoring efforts are better directed at those systems which are most likely to be contaminated by man-made radioactivity. However, the State should require monitoring for man-made radioactivity in each principal watershed under its jurisdiction as necessary to determine the extent of radioactivity in surface waters. The regulations have been so amended.

Commentors representing consumers, States, and industry objected to the provision that discharge data from nuclear facilities could be used in lieu of monitoring for man-made radioactivity. This provision has been redrafted to reflect more adequately the intention of this provision. Suppliers may use data obtained through an environmental surveillance program conducted by a nuclear facility in conjunction with the State to show compliance with these regulations. In many cases these monitoring programs will include more complete and frequent analyses of radioactivity in source and finished waters than would normally be available through State efforts alone.

A few comments stated that the proposed monitoring for specific radionuclides in the vicinity of nuclear facilities would often be unnecessary and that if such tests could be preceded by a screening test for gross beta particle activity, monitoring costs would be reduced. EPA agrees with these comments as they apply to the required quarterly monitoring for strontium-89 and cesium-134. The regulations concerning monitoring in the vicinity of nuclear facilities have been amended to establish a screening level for gross beta particle activity of 15 pCi/1. Only if this concentration is exceeded is measurement of strontium-89 and cesium-134 required. Tritium and iodine-131 are not measured by a test for gross beta particle activity and the requirement for analyses for these radionuclides is retained.

Some commentors pointed out that monitoring for iodine-131 ,as proposed was unrealistic since a single "grab" sample per quarter might not detect intermittent discharges from nuclear facilities. Other commentors stated that the decay of iodine-131 would render any measurements meaningless. While there is merit in both arguments, continuous monitoring for iodine-131 is impractical in many cases because of cost considerations. However, monitoring for iodine-131 will be more meaningful if, each quarter, a sample based on five successive daily composites is measured, as required in the revised regulations. This measurement should be made as soon as possible after collection and appropriate decay corrections applied as outlined in *Interim Radiochemical Methodology for Drinking Water*, referenced in S141.25(a).

Several commentors requested supplemental information on the storage and analysis of composited quarterly samples. Additional comments questioned the feasibility of compositing quarterly samples for iodine-131 monitoring and the need to correct for decay between the time samples are collected and measured. The required treatment for the preservation of composited samples is discussed in both the Statement of Basis and Purpose and the reference cited above. In the case of iodine-131, hydrochloric rather than nitric acid should be used for acidification and sodium bisulfite should be added to the sample.

A few commentors requested that cesium-137 be included with cesium-134 in the monitoring program for man-made radioactivity. The Administrator believes, in the interest of cost, that only one cesium isotope measurement should be mandatory. Measurement of cesium-134, which provides more information on changes in environmental levels than cesium-137 monitoring, is preferable. However, States may include cesium-137 monitoring if they desire to do so. In many cases costs will not be affected significantly. When beta activity exceeds 50 pCi/l, identification of major radioactive constituents is required. The extent of such analysis should be based on the States' determination of what radionuclides are likely to be present in the water and the maximum dose that could be delivered by unidentified components.

A few commentors requested additional guidance on calculating the concentration of radioactivity yielding 4 mrem per year, based on NBS Handbook 69, as required by these Regulations. The Administrator anticipated this problem and the Agency is publishing a revised Statement of Basis and Purpose which includes a table giving the concentration that is calculated to result in a dose equivalent rate of 4 mrem per year from all radionuclides of interest. The revised Statement also contains other pertinent information needed to facilitate compliance with these regulations.

PART II

General Comments

Monitoring and treatment costs

Many comments were received on the Agency's estimate of monitoring costs under these proposed regulations. One State supplied cost estimates which were lower than analytical costs estimated in the preamble. Another State thought that cost estimates in the preamble "were about right." However, all other commentors thought that the cost estimates made by EPA were too low. There are several reasons for this difference of opinion. In some cases commentors provided an analysis of their estimated cost for compliance based on sampling frequencies in excess of those required by the proposed regulations and the use of additional test analyses not required by the regulations. Another source of difficulty was that, as stated in the preamble, the cost per sample did not include collection and shipping charges. One State estimated this cost as high as $15.00 per sample. No other examples were provided, however. This Agency's cost for obtaining one gallon water samples for its Eastern Environmental Radiation Facility in Alabama is, exclusive of labor costs: container cost, $.62; shipping empty, $1.00; return full container, $2.00. Since analyses for gross alpha particle activity and radium require less volume, States costs for most community water supplies should be lower.

A major source of disparity between Agency and commentor cost estimates was that the EPA estimates did not include capital equipment costs. This is particularly important for States having essentially no ongoing program for measuring radioactivity in water. In such cases the cost estimates will be exceeded if a new laboratory program must be established. In most cases, however, State laboratories are available with at least some equipment for initiating the required monitoring program.

Two states objected to the monitoring costs for natural radioactivity on the basis that they were not cost effective for small public water systems. They contended that monitoring should be restricted to large community water supplies. The Administrator believes that the requirements of the Safe Drinking Water Act are such that the quality of water served by community water supply systems should be independent of the population size to the extent feasible. It will be more expensive, in some cases, on a per person basis to monitor very small systems, but such costs are not impractical for even the smallest community water system. However, in the case of man-made radioactivity, the nature of the potential hazard, the availability of laboratory facilities and the cost of monitoring do justify limiting required monitoring to large community water systems, serving more than 100,000 persons, community systems impacted by nuclear facilities, systems using water from major watersheds, and such other systems as are designated by the State.

Other groups pointed out that on the whole the monitoring cost per person served is trivial and objected to the aggregation of national costs in the preamble. EPA believes that the national costs as well as the cost to individual community water systems, are worthy of consideration.

One commenter believed that the number of community water systems impacted by nuclear facilities had been underestimated because the number of nuclear facilities would increase markedly in the future and many community water systems would be impacted by a single nuclear facility. It is true that the number of nuclear facilities that will necessitate monitoring of community water systems will increase in the future. The cost estimates in the preamble were based on an assumed average of one and a half community water systems being impacted by each nuclear facility. The commenter believed two would be impacted by each nuclear facility in his State.

Another commentor wanted to know if all drinking water regardless of source would be monitored for both alpha particle and beta particle radioactivity. The Regulations are specific on this point. Systems utilizing only ground water need not monitor for man-made beta particle radioactivity. Sources using surface water must monitor for both beta and alpha particle activity if they serve more than 100,000 persons, utilize surface water which may be contaminated by effluents from nuclear facilities, or as required by the State. Other surface water systems need not monitor for man-made radioactivity. However, it is recommended that all systems be monitored for gross beta particle activity.

A large number of respondents were concerned with the number and adequacy of existing monitoring facilities and the costs connected with establishing supplemental facilities. In some cases existing monitoring facilities may not be adequate. The situation will be more severe for those jurisdictions where the gross alpha particle concentration exceeds the screening level. However, the higher screen level in the revised regulation will reduce the number of mandatory radium analyses by a factor of two or more.

Moreover, the phased monitoring requirements imposed by these regulations should provide adequate time for State and private laboratories to add necessary facilities and equipment. It is true that many small systems will be required to monitor for gross alpha activity and, in the aggregate, bear the major cost impact of the monitoring requirements. However, it is precisely these systems which are most likely to be contaminated with natural radioactivity. There is no question but that additional funds will be required for such increased monitoring. It was the intent of Congress that these costs be borne by the individual public water systems and that corrective measures, such as consolidation of smaller systems, be employed to ameliorate this effect.

A few commentors questioned whether the proposed limits were "cost effective" in terms of both treatment and monitoring costs. As stated in the preamble to the proposed regulations, selection of an appropriate maximum contaminant level was not based solely on the estimated cost effectiveness of radium removal. As explained in the Statement of Basis and Purpose, the health risk estimates are uncertain by at least a factor of four. However, the difference in cost-effectiveness between different control levels is independent of this uncertainty and therefore provides information on where cost-benefit ratios become significantly poorer. The Statement of Basis and Purpose also examines why the cost-effectiveness of radium removal by ion exchange is low and suggests alternative approaches to obtaining maximum contaminant levels at lower costs. The cost-effectiveness of the required monitoring program will depend on the number of supplies identified as exceeding the maximum contaminant limits. This cannot be forecast until the initial monitoring is completed. In any event, a strict cost-effectiveness approach is not the intent of the Safe Drinking Water Act. Maximum contaminant levels are to prevent adverse health effects to the extent feasible.

One commentor interpreted a statement in the Preamble concerning future review of these regulations to indicate that the purpose of the Proposed Regulations was to conduct a national field survey for radioactivity in drinking water at State expense. A second comment expressed a similar opinion regarding monitoring requirements for man-made radioactivity.

The Proposed Regulations are based on the Administrator's determination that they protect health to the extent feasible after taking treatment costs into consideration. He is aware that the Agency's estimates of national cost are dependent on the number of community water systems impacted and that an adequate estimate of their number is not available now. By Congressional mandate these are interim regulations subject to revision in 1978. The Administrator would be remiss if he were to ignore new data on the impact of these regulations as it becomes available as an outgrowth of the reporting requirement.

Another commentor asked why the Agency had not set the limit for man-made radioactivity using a cost-benefit approach. The Agency does not believe such an approach is either practicable or needed at this time. Present levels of man-made radioactivity in community water systems are quite low—a statement supported in Appendix III of the Statement of Basis and Purpose and there is no evidence that allowing higher concentrations in drinking water would confer significant reductions in compliance costs. Effluent control costs are not likely to be changed by the proposed regulations for man-made radioactivity. Effluent control practices of the nuclear industry as currently regulated appear to be adequate in terms of the proposed maximum contaminant limits. The Agency does not believe it was the intention of Congress that the cost of removing man-made radioactivity from public water systems should be balanced against the cost of effluent controls required by regulations established under other legislation.

Calculational models used

One commentor objected to the statement in the preamble concerning the estimated dose due to drinking water contaminated by currently operating nuclear fuel cycle components. The objection was based on two points.

(1) That these estimates were based on calculational models, which may not accurately reflect reality.

(2) That the estimates do not consider aerial depositions from radioactive materials which are initially deposited into air and then fall out onto the ground and are washed into waterways.

The Administrator believes the best calculational models currently available were used for these estimates. Measurement of the actual doses is, of course, impossible at these low levels. As stated in the Statement of Basis and Purpose, the Administrator will consider new models as they are proposed by appropriate organizations and modify the proposed regulations as necessary to reflect new information as it becomes available. By basing compliance with maximum contaminant levels on measured concentrations of radioactivity in finished drinking water the Administrator believes aerial deposition as a source of water contamination is adequately considered.

Public water systems impacted

One commentor stated that the monitoring data included in the Statement of Basis and Purpose for community water systems were not representative of the radium or alpha particle radioactivity in sections of the country having abnormally high concentrations of natural radioactivity and therefore EPA's estimates of the impact of the proposed regulations were unrealistic. The Agency believes that the data given in the Appendix to the Statement of Basis and Purpose were representative of the country as a whole, but agrees there are sections of the country which routinely have higher amounts of radium in their community water systems. However, as stated in the Statement of Basis and Purpose, these national data were not used as a basis for the EPA estimate of the number of public water systems impacted by the proposed maximum contaminant limit for radium. Rather, that estimate is based on other monitoring data obtained mostly in regions where significant amounts of radium are commonly found in community water systems, as referenced in the Statement.

Linear nonthreshold response functions

One commentor stated the Agency was too conservative in the estimation of possible health effects because a linear nonthreshold dose response function was assumed. Another commentor stated a linear nonthreshold relationship is not conservative enough since an increased radiocarcinogenic response has been associated with low dose rates from alpha particle irradiation. Conversely, one commentor stated that there is a threshold for radiation injury from ingested radium and that the maximum contaminant level for radium should be based on his value for a threshold dose. Reasons for using a linear nonthreshold dose response were given in full in the Statement of Basis and Purpose and are reproduced here as Part III of this Appendix. The Agency is aware that one study on the results of clinical treatments with radium-224 indicates that protraction of the alpha exposure is more carcinogenic and that it has been hypothesized that lung cancer may be associated with very low dose rates from alpha particle emitters. Also, analyses of the radium dial painter data have been interpreted as indicating that bone cancers from lower radium doses occur later in life than from large doses and this has been interpreted as an argument for an effective threshold. However, the United States Public Health Service has studied this question in some detail, BRH/DBE 70-5, and EPA agrees with the USPHS finding that the data are insufficient to specify an unequivocal dose response model and their conclusion that, "* * * in the low dose region expected to be experienced by the general public, the assumption of a linear nonthreshold model continues to be a prudent public health philosophy for standards setting."

MISCELLANEOUS

Two States requested a definition of "nuclear facility." As explained in the Statement of Basis and Purpose, the term "nuclear facility" is flexible so that the States may determine which community water systems require additional monitoring. The term "nuclear facility" should not be construed as applying only to nuclear electric-generating plants and other components in the uranium fuel cycle but may also include, at the option of the State, waste storage areas, experimental facilities, and medical centers as outlined in the Statement of Basis and Purpose.

Four commentors believed that the proposed regulations would be difficult for persons working in community water systems to understand—that they were too technical. EPA agrees this is a highly technical subject not amenable to lay terms. However, the Agency has attempted to clarify the regulations and believes that all States have radiological health personnel who are willing to assist a supplier of water if particular problems of interpretation arise.

Several commentors expressed the opinion that data collected prior to implementation of the proposed regulations should be admissible as evidence of compliance. EPA agrees and the regulations have been modified so that analytical data acquired one year prior to the effective date of these regulations may be substituted for monitoring required during the initial period at the discretion of the State. This should reduce initial monitoring costs.

Two commentors expressed concern about adverse health effects that might occur as a result of sodium addition to water during the zeolite softening process. Possible health effects from sodium were considered in detail by the Agency in the development of the proposed regulations for inorganic chemicals, as well as for radium, and are discussed in the Statement of Basis and Purpose. The

Agency believes it not appropriate to set a maximum contaminant level for sodium. The consensus of opinion among medical personnel in this field is that, while the sodium added is not negligible, patients on a restricted, but noncritical, sodium diet would not be adversely affected at the increased levels contemplated. Patients for whom the increased levels might be critical are not normally permitted to use regular drinking water supplies but are restricted to specially processed water. The Statement of Basis and Purpose recommends that community physicians having patients in areas where the concentration of sodium is increased due to radium removal be so informed by the supplier.

One commentor took exception to the suggestion in the preamble that, taken as a whole, releases from hospitals and other industrial facilities would result in doses comparable to those released from nuclear facilities such as light water reactors. The statement in the preamble was not based on a full scale technical evaluation. The Agency is studying releases of radioactive materials from hospitals and other complexes through contractor research and will amend this estimate as necessary based on these and other findings.

Several respondents were in doubt as to the responsibilities of the water supplier in terms of actual performance of the required analyses. Allied questions were directed to whether the supplier of water or the State is responsible for the cost of analyses.

It is the intent of the regulations that the individual water supplier, while responsible for compliance with the regulations, may reasonably be expected to collect and transmit water samples to approved laboratories for actual performance of the radioanalysis. It is the intent of both Congress and these regulations that the principal costs associated with compliance with the Safe Drinking Water Act be borne by the individual public water systems. However, a State is not barred from analyzing samples for public water systems without charge.

One commentor wanted to know if the proposed maximum contaminant levels for radioactivity in drinking water replaced Federal Radiation Council Guidance on Radiation Protection Guides for the general population. These regulations do not replace FRC recomendations on the transient intake of radioactive materials, which included both the food and water pathways, and which contemplated, except in the case of radium, exposures of less than a lifetime duration. EPA believes that the FRC Range II limit for large population groups cannot be applied to a single pathway, such as drinking water, since FRC Guides include exposure from external radiation, inhaled radioactivity and radioactivity in food as well as drinking water.

Three commentors questioned basing the maximum contaminant limits on the same dose limit whether applied to any internal organ or to the whole body. EPA has considered this question with care in developing these regulations, recognizing that the conservatism of the maximum contaminant limits was increased by this decision. The decision not to consider critical organs for the ingestion of radioactivity in drinking water is based on the National Committee on Radiation Protection (NCRP) recommendations contained in NCRP Report No. 39. In that report, the NCRP recommended that organ dose limits for the general population be based on whole body dose and not at a fraction of the corresponding *occupational dose limit* for critical organs. The NCRP decision was in part based on the lack of data available at that time to consider appropriately the risk from a radiation insult to various organs. Such data are becoming available now and the International Commission on Radiation Protection (ICRP) is considering basing dose limits on the risk to various organ systems. When the ICRP recommendations are developed in final form they will be considered by EPA.

PART III

ORP Policy Statement on the Relationship Between Radiation Dose and Effect; March 3, 1975

The actions taken by the Environmental Protection Agency to protect public health and the environment require that the impacts of contaminants in the environment or released into the environment be prudently examined. When these contaminants are radioactive materials and ionizing radiation, the most important impacts are those ultimately affecting human health. Therefore, the Agency believes that the public interest is best served by the Agency providing its best scientific estimates of such impacts in terms of potential ill health.

To provide such estimates, it is necessary that judgments be made which related the presence of ionizing radiation or radioactive materials in the environment, i.e., potential exposure, to the intake of radioactive materials in the body, to the absorption of energy from the ionizing radiation of different qualities, and finally to the potential effects on human health. In many situations the levels of ionizing radiation or radioactive materials in the environment may be measured directly, but the determination of resultant radiation doses to humans and their susceptible tissues is generally derived from pathway and metabolic models and calculations of energy absorbed. It is also necessary to formulate the relationship between radiation dose and effects; relationships derived primarily from human epidemiological studies but also reflective of extensive research utilizing animals and other biological systems.

Although much is known about radiation dose-effect relationships at high levels of dose, a great deal of uncertainty exists when high level dose-effect relationships are extrapolated to lower levels of dose, particularly when given at low dose rates. These uncertainties in the relationships between dose received and effect produced are recognized to relate, among many factors, to differences in quality and type of radiation, total dose, dose distribution, dose rate, and radiosensitivity, including repair mechanisms, sex, variations in age, organ, and state of health. These fatcors involve complex mechanisms of interaction among biological chemical, and physical systems, the study of which is part of the continuing endeavor to acquire new scientific knowledge.

Because of these many uncertainties, it is necessary to rely upon the considered judgments of experts on the biological effects of ionizing radiation. These findings are well-documented in publications by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Academy of Sciences (NAS), and the National Council on Radiation Protection and Measurements (NCRP), and have been used by the Agency in formulating a policy on relationship between radiation dose and effect.

It is the present policy of the Environmental Protection Agency to assume a linear, nonthreshold relationship between the magnitude of the radiation dose received at environmental levels of exposure and ill health produced as a means to estimate the potential health impact of actions it takes in developing radiation protection as expressed in criteria, guides, or standards. This policy is adopted in conformity with the generally accepted assumption that there is some potential ill health attributable to any exposure to ionizing radiation and that the magnitude of this potential ill health directly proportional to the magnitude of the dose received.

In adopting this general policy, the Agency recognizes the inherent uncertainties that exist in estimating health impact at the low levels of exposure and exposure rates expected to be present in the environment due to human activities, and that at these levels the actual health impact will not be distinguishable from natural occurrences of ill health, either statistically or in the forms of ill health present. Also, at these very low levels, meaningful epidemiological studies to prove or disprove this relationship are difficult, if not practically impossible to conduct. However, whenever new information is forthcoming, this policy will be reviewed and updated as necessary.

It is to be emphasized that this policy has been established for the purpose of estimating the potential human health impact of Agency actions regarding radiation protection, and that such estimates do not necessarily constitute identifiable health consequences. Further, the Agency implementation of this policy to estimate potential human health effects presupposes the premise that, for the same dose, potential radiation effects in other constituents of the biosphere will be no greater. It is generally accepted that such constituents are not more radiosensitive than humans. The Agency believes the policy to be a prudent one.

In estimating potential health effects it is important to recognize that the exposures to be usually experienced by the public will be annual doses that are small fractions of natural background radiation to at most a few times this level. Within the U.S. the natural background radiation dose equivalent varies geographically between 40 to 300 mrem per year. Over such a relatively small range of dose, any deviations from dose-effect linearity would not be expected to significantly affect actions taken by the Agency, unless a dose-effect threshold exists.

While the utilization of a linear, nonthreshold relationship is useful as a generally applicable policy for assessment of radiation effects, it is also EPA's policy in specific situations to utilize the best available detailed scientific knowledge in estimating health impact when such information is available for specific types of radiation, conditions of exposure, and recipients of the exposure. In such situations, estimates may or may not be based on the assumptions of linearity and a nonthreshold dose. In any case, the assumptions will be stated explicitly in any EPA radiation protection actions.

The linear hypothesis by itself precludes the development of acceptable levels of risk based solely on health considerations. Therefore, in establishing radiation protection positions, the Agency will weigh not only the health impact, but also social, economic and other considerations associated with the activities addressed.

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APPENDIX B

NATIONAL SECONDARY DRINKING WATER REGULATIONS

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NATIONAL SECONDARY DRINKING WATER REGULATIONS

Proposed Regulations

ENVIRONMENTAL PROTECTION AGENCY

[40 CFR Part 143]

NATIONAL SECONDARY DRINKING WATER REGULATIONS

Proposed Regulations

Notice is hereby given that pursuant to section 1412 of the Public Health Service Act, as amended by the Safe Drinking Water Act ("the Act," Pub. L. 93-523), the Administrator of the Environmental Protection Agency (EPA) proposes to issue a new 40 CFR Part 143 setting forth Secondary Drinking Water Regulations.

The Act was signed by the President on December 16, 1974. It is the first Federal Act dealing in depth with providing safe drinking water for public use. National Interim Primary Drinking Water Regulations were proposed on March 14, 1975, and promulgated on December 24, 1975. Regulations covering radionuclides were added on July 9, 1976. The regulations proposed today, the secondary regulations, follow and complement the primary regulations. While primary regulations are devoted to constituents and regulations affecting the health of consumers, secondary regulations are those which deal with the esthetic qualities of drinking water. The contaminants for which Secondary Maximum Contaminant Levels are set in these regulations may not have a significant direct impact on the health of consumers, but their presence in excessive quantities may discourage the utilization of a drinking water supply by the public.

Primary drinking water regulations are applicable to all public water systems and are enforceable by EPA or the States which have accepted primacy; secondary regulations are not Federally enforceable and are intended as guidelines for the States. EPA expects the States to give priority attention to implementation of the mandatory primary regulations which provide health requirements.

Section 1414 of the Act provides:

> (d) Whenever, on the basis of information available to him, the Administrator finds that within a reasonable time after National Secondary Drinking Water Regulations have been promulgated, one or more public water systems in a State do not comply with such secondary regulations, and that such noncompliance appears to result from a failure of such State to take reasonable action to assure that public water systems throughout such State meet such secondary regulations, he shall so notify the State.

EPA does not propose to use its resources, on a routine basis, to independently determine compliance or noncompliance with the secondary regulations. It will, however, review data which may be reported by the States on a discretionary basis or which is received incidental to other studies. On the basis of such review, the agency will consult with the States to determine the action taken by them to assure compliance and where appropriate, notify States of noncompliiance which has not been acted on.

SECONDARY MAXIMUM CONTAMINANT LEVELS

The Secondary Drinking Water Regulations contain maximum contaminant levels for chloride, color, copper, corrosivity, foaming agents, hydrogen sulfide, iron, manganese, odor, pH, sulfate, total dissolved solids and zinc. Brief statements on the effects of these on water quality are listed, and more detailed comments are available in the Statement of Basis and Purpose, available as described in the last section of the preamble.

Chloride in reasonable concentrations is not harmful to humans, but in concentrations above 250 mg/l chloride causes a salty taste in water which is objectionable to many people. Chloride can be removed from drinking water by distillation, reverse osmosis or electrodialysis, but in some cases the entry of chloride into a drinking water source can be minimized by proper aquifer selection and well construction.

Color may be indicative of dissolved organic material which may lead to generation of trihalomethanes and other organohalogen compounds during chlorination. Color can also be caused by inorganic species such as manganese or iron. Color becomes objectionable and unesthetic to most people at levels over 15 C.U. (Color Units). In some cases, color can be objectionable at the 5 C.U. level, and States, therefore, should also consider the regulation of color at levels below 15 C.U. Depending on the nature of the substances causing color, conventional water treatment (flocculation and filtering), oxidation or carbon adsorption are processes used for removing color.

Copper is an essential and beneficial element in human metabolism, but copper imparts an undesirable taste to drinking water. Small amounts of copper are generally regarded as nontoxic. Copper can be removed from water by ion exchange, and by proper control of pH, where the source of copper is the corrosion of copper pipes.

Corrosivity is a complex characteristic of water related to pH, alkalinity, dissolved oxygen and total dissolved solids plus other factors. A corrosive water, in addition to dissolving metals with which it comes in contact, also produces objectionable stains on plumbing fixtures. Corrosivity is controlled by pH adjustment, the use of chemical stabilizers, or other means which are dependent upon the specific conditions of the water system.

The corrosivity of drinking water is a parameter which has not only esthetic significance, but health and economic significance as well. The products of corrosion having the greatest health significance, cadmium and lead, are addressed in primary regulations, but there is also a sufficient basis to include corrosivity in secondary regulations. The problem lies in the lack of a simple, generally acceptable means for measuring the corrosivity of water and thus the lack of a generally acceptable numerical index for assessing and limiting corrosivity. There are a number of indices in use, but no agreement on a single one which would, in all cases, definitively say whether or not a given water was corrosive. An attempt to circumvent the problem can be made by specifying, in lieu of an index, practical tests of corrosivity using pipe sections, metal coupons or water analyses for the determination of the corrosive properties of a water. Unfortunately, most of these tests, as well as most indices, are not universally applicable and require long periods of time to carry out or develop. For a corrosivity test or index to be widely used and applied, the testing procedure must be rapid, simple and generally applicable. Comments are solicited from the public on a practical means for assessing corrosivity, as well as an associated number to be used as a Secondary Maximum Contaminant Level.

Foaming is a characteristic of water caused principally by the presence of detergents and similar substances. Water which foams is definitely unesthetic and considered unfit for consumption. The foamability of water is measured by the quantity of methylene blue active substances (MBAS) present. Foaming substances can be removed from drinking water by carbon adsorption, but it is preferable to prevent contamination of water by these substances.

Hydrogen sulfide is an odorous gas. Its presence in drinking water is often attributed to microbial action on organic matter or the reduction of sulfate ions to sulfide. In addition to its obnoxious odor, hydrogen sulfide in association with soluble iron produces black stains on laundered items and black deposits on piping and fixtures. Hydrogen sulfide is removed from drinking water by aeration or chemical oxidation.

Iron is a highly objectionable constituent of water supplies for either domestic or industrial use. Iron may impart brownish discolorations to laundered goods. The taste that it imparts to water may be described as bitter or astringent, and iron may adversely affect the taste of other beverages made from water. The amount of iron causing objectionable taste or laundry staining constitutes only a small fraction of the amount normally consumed in the daily diet and thus does not have toxicologic significance. Iron can be removed from water by conventional water treatment processes or ion exchange and also by oxidation processes followed by filtering. If the iron comes from the corrosion of iron or steel piping the problem can often be eliminated by practicing corrosion control.

Manganese, like iron, produces discoloration in laundered goods and impairs the taste in drinking water and beverages, including tea and coffee. At concentrations in excess of 0.05 milligrams per liter, manganese can occasionally cause buildup of coatings in distribution piping which can slough off and cause brown spots in laundry items and unethetic black precipitates. Managanese can usually be removed from water by the same process used for iron removal.

Odor is an important esthetic quality of water for domestic consumers and process industries such as food, beverage and pharmaceutical manufacturers, which require water essentially free of taste and ordor. It is usually impractical and often impossible to isolate and identify the odor-producing chemical. Evaluation of odors and tastes is thus dependent on the individual senses of smell and taste. In many cases, sensations ascribed to the sense of taste are actually odors. Odors are usually removed by carbon adsorption or aeration.

The range of pH in public water systems may have a variety of esthetic and health effects. Corrosion effects are commonly associated with pH levels below 6.5. As pH levels are increased to above 8.5 mineral incrustations and bitter taste can occur, the germicidal activity of chlorine is substantially reduced and the rate of formation of trihalomethanes is significantly increased. However, the impact of pH in any one water system will vary depending on the overall chemistry and composition of the water so that a more or less restrictive range may be appropriate under specific circumstances.

Sulfate may cause detectable tastes at concentrations of 300–400 milligrams per liter; at concentrations above 600 milligrams per liter it may have a laxative effect. High concentrations of sulfate also contribute to the formation of scale in boilers and heat exchangers. Sulfate can be removed from drinking water by distillation, reverse osmosis or electrodialysis. The laxative effect noted above seldom affects regular users of the water but transients are particularly susceptible. For this reason it is recommended that States institute monitoring programs for sulfate, and that transients be notified if the sulfate content of the water is high. Such notification should include an assessment of the possible physiological effects of consumption of the water.

Total Dissolved Solids (TDS) may have an influence on the acceptability of water in general, and in addition a high TDS value may be an indication of the presence of an excessive concentration of some specific substance that would be esthetically objectionable to the consumer. Excessive hardness, taste, mineral deposition or corrosion are common properties of highly mineralized water. Dissolved solids can be removed by chemical precipitation in some cases, but distillation, reverse osmosis, electrodialysis and ion exchange are more generally applicable.

Zinc, like copper, is an essential and beneficial element in human metabolism. Zinc can also impart an undesirable taste to water. At higher concentrations, zinc salts impart a milky appearance to water. Zinc can be removed from water by conventional water treatment processes or ion exchange, but since the source of zinc is often the coating of galvanized iron, corrosion control will minimize the introduction of zinc into drinking water. At the same time, corrosion control will minimize the introduction of lead and cadmium into the drinking water, since lead and cadmium are often contaminants of the zinc used in galvanizing.

Contaminants Considered But Not Included In The Regulations

In addition to the above contaminants, several other drinking water parameters were considered for inclusion in these regulations. Among these are hardness, alkalinity, phenols, sodium and standard plate count.

Since high levels of hardness have significant esthetic and economic effects, the removal of hardness (softening) can be considered beneficial from a non-health standpoint. However, correlations between the softness of water and the incidence of cardiovascular disease have been shown, in some studies, so the practice of softening drinking water is being discouraged by some scientists and physicians. Available information is not sufficient at this time to balance the esthetic desirablty of settng a limit for hardness against the potential health risk of water softening.

Phenols, particularly the chlorophenols, are esthetically objectionable because of the taste and ordor they produce. Some of the chlorophenols produce a detectable taste or odor at concentrations as low as 1 ppb. While analysis for phenols in this concentration area might present some difficulties, the odor test can easily detect the presence of these compounds and thus makes the inclusion of a limit for phenols unnecessary.

The principal concern with respect to sodium relates to its potential health significance rather than to esthetic effects. However, existing data did not support the establishment of a Maximum Contaminant Level for sodium in the Interim Primary Drinking Water Regulations. It is recommended that the States institute programs for regular monitoring of the sodium content of drinking water served to the public, and for informing physicians and consumers of the sodium concentration in drinking water. By this means, those affected by high sodium concentrations can make adjustments to their diets, or seek alternative sources of water to be used for drinking and food preparation.

It has been suggested that standard plate count, a measure of bacterial concentration, be included as an esthetic parameter in these regulations but it causes no observable esthetic effect and consequently is not appropriate for inclusion. Microbiological MCL's are contained in the National Interim Primary Regulations.

Monitoring

Since these regulations are not Federally enforceable, there are no associated monitoring requirements. As a practical minimum, however, it is recommended that the contaminants listed in these regulations be monitored along with the inorganic chemicals monitored to determine compliance with the primary regulations. Obviously, some parameters are subject to frequent variations and, therefore, may need to be monitored more frequently. The States may wish to supplement these regulations with more specific monitoring requirements in their own laws and regulations.

Economic Impact

As noted above, the Secondary Drinking Water Regulations are not Federally enforceable, so the extent of their implementation and thus the associated economic impact is impossible to judge. However, since there are data available on the prevalence of some of the contaminants listed in these regulations and since treatment costs are also available, a limited economic evaluation has been prepared. Actual compliance will depend on the level of State implementation, and customer dissatisfaction and willingness to pay for improvements.

The limited evaluation considers cost impacts on consumers in different size systems for treatment to remove iron and manganese and to adjust pH levels for corrosion control. It demonstrates that esthetic parameters are exceeded most often in small water systems with only a low rate of exceeders in the larger systems. For example, in the National Community Water Supply Study, 25 percent of the systems failed at least one esthetic limit but this represented only 12 percent of the study population; conversely 88 percent of the study population had esthetically satisfactory water.

The per-customer costs of providing iron and manganese control and pH adjustment for corrosion control were substantially greater for small water systems than for the large systems. The monthly cost per household was estimated at $3.60 (25–99 persons served) as against $1.10 for systems serving over 100,000 and recent field data indicate that the small system costs may be much higher under some circumstances. These data may provide the reason for the probable existence of more frequent esthetic quality problems in small systems where the customer may be willing to accept a lower esthetic quality water rather than to pay higher treatment costs. These cost data can be used by States and communities as indicators of approximate cost of compliance. Further information regarding the economic evaluation may be obtained from the Office of Water Supply.

Comments and Public Hearing

Interested persons may participate in this rulemaking process by submitting written comments in triplicate to the Office of Water Supply (WH-550), Criteria and Standards Division, Environmental Protection Agency, Washington, D.C. 20460.

During the development of these proposed regulations, additional suggestions were received, including a recommendation that, for Total Dissolved Solids, chloride and sulfate, three different levels be set (1) a Recommended Level, (2) an Upper Limit and (3) a Short-Term Limit. The Recommended Level would represent the desirable concentration for a high degree of consumer acceptance; the Upper Limit would be acceptable when it is not reasonably feasible to provide more suitable water; and the Short-Term Limit would be considered acceptable only for existing systems pending construction of treatment facilities or development of new water sources. Other suggestions were that more frequent monitoring be recommended for constituents, such as color and odor, whose concentrations vary from day to day. Sodium has also been suggested for inclusion in the secondary MCL's.

Comments on the above and all other aspects of the proposed regulations, particularly corrosivity measuring methods, are solicited. Comments regarding additional contaminants or the deletion of any of the listed contaminants, as well as comments regarding the proposed Secondary Maximum Contaminant Levels will be welcome. All comments received on or before June 1, 1977, will be considered. Later comments will be considered as time permits.

Copies of the Statement of Basis and Purpose for these Proposed Secondary Drinking Water Regulations and other relevant documents will be available after April 1, 1977, from the EPA Public Information Reference Unit, Room 2922, Waterside Mall, 401 M Street, S.W., Washington, D.C. 20460. A copy of all public comments and transcripts of the public hearing will be available for inspection and copying from the EPA Public Information Reference Unit. For public review and copying, the EPA Information Regulation (40 CFR Part 2) provides that a reasonable fee may be charged for the copying service.

In addition to considering public comments sent to EPA, the Agency will hold a public hearing at Room 2117, EPA Headquarters, Waterside Mall, 401 M Street, S.W., Washington, D.C. 20460 on May 3, 1977 beginning at 9:30 AM. Persons who wish to make statements at this hearing should register with Dr. Joseph A. Cotruvo, Director, Criteria and Standards Division, Office of Water Supply by April 29, 1977 (202-755-5643) and are urged to submit written copies of their remarks in triplicate at the time they are presented for inclusion in the record.

Dated: March 21, 1977.

DOUGLAS M. COSTLE,
Administrator.

It is proposed to amend Chapter I of Title 40 of the Code of Federal Regulations by adding Part 143, as follows:

PART 143—NATIONAL SECONDARY DRINKING WATER REGULATIONS

Sec.
143.1 Purpose
143.2 Definitions
143.3 Secondary Maximum Contaminant Levels
143.4 Monitoring

AUTHORITY: Sec. 1412(c) of the Public Health Service Act, 68 Stat. 1660 (42 USC 300g-1)

§ 143.1 Purpose.

This part establishes Secondary Drinking Water Regulations pursuant to Section 1412 of the Public Health Service Act, as amended by the Safe Drinking Water Act (Pub. L. 93-523).

§ 143.2 Definitions.

(a) "Act" means the Public Health Service Act as amended by the Safe Drinking Water Act, Pub. L. 93-523.

(b) "Contaminant" means any physical, chemical, biological, or radiological substance or matter in water.

(c) "Secondary Maximum Contaminant Level" means the advisable maximum level of a contaminant in water which is delivered to the free-flowing outlet of the ultimate user of a public water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

(d) "Public water system" means a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals daily at least 60 days out of the year.

(e) "State" means the agency of the State government which has jurisdiction over public water systems.

(f) "Supplier of water" means any person who owns or operates a public water system.

§ 143.3 Secondary maximum contaminant levels.

The Secondary Maximum Contaminant Levels for public water systems are as follows:

Contaminant:	*Level*
Chloride	250 mg/l.
Color	15 Color Units.
Copper	1 mg/l.
Corrosivity	Non-corrosive.
Foaming Agents	0.5 mg/l.
Hydrogen Sulfide	0.05 mg/l.
Iron	0.3 mg/l.
Manganese	0.05 mg/l.
Odor	3 Threshold Odor Number.
pH	6.5-8.5.
Sulfate	250 mg/l.
TDS	500 mg/l.
Zinc	5 mg/l.

§ 143.4 Monitoring.

(a) It is recommended that the parameters in these regulations should be monitored at intervals no less frequent than the monitoring performed for inorganic chemical contaminants listed in the National Interim Primary Drinking Water Regulations as applicable to community water systems. More frequent monitoring may be appropriate for specific parameters under certain circumstances or may be directed by the State.

(b) Analyses conducted to determine compliance with § 143.3 should be made in accordance with the following methods:

(1) Chloride—Potentiometric Method, "Standard Methods for the Examination of Water and Wastewater," 14th Edition, P. 306.

(2) Color—Platinum-Cobalt Method, "Methods for Chemical Analysis of Water and Wastes," pp. 36-38, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974. or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 160-162, 14th Edition, p. 64.

(3) Copper—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes, pp. 108-109, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater,: 13th Edition, pp. 210-215, 14th Edition p. 144.

(4) Corrosion—Reserved.

(5) Foaming Agents—Methylene Blue Method, "Methods for Chemical Analysis of Water and Wastes," pp. 157-158, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater, 13th Edition, pp. 337-342, 14th Edition, p. 600.

(6) Hydrogen Sulfide—Titrimetric Iodine Method, "Methods for Chemical Analysis of Water and Wastes," p. 284, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 551-555, 14th Edition, p. 505.

(7) Iron—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 110-111, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, p. 144.

(8) Manganese—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 116-117, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, p. 144.

(9) Odor—Consistent Series Method, "Methods for Chemical Analysis of Water and Wastes," pp. 287-294, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 248-254, 14th Edition, p. 75.

(10) pH—Glass Electrode Method "Methods for Chemical Analysis of Water and Wastes," pp. 239-240, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 276-281, 14th Edition, pp. 460-465.

(11) Sulfate—Turbidimetric Method, "Methods for Chemical Analysis of Water and Wastes," pp. 277-278, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 334-335, 14th Edition, p. 496.

(12) Total Dissolved Solids—Total Residue Method, "Methods for Chemical Analysis of Water and Wastes," pp. 270-271, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 288-290, 14th Edition, p. 91.

(13) Zinc—Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 155-156, Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, p. 144.

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